Pushing the Boundaries of Freshwater Ecosystem Restoration: Evaluating a Conservation Initiative in Terms of Social-Ecological Resilience

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Abstract

Freshwater ecosystems are among the most transformed systems on Earth despite their critical importance to human well-being. This research utilized a single case, embedded case study design to explore the possibility of an approach to aquatic ecosystem restoration informed by social-ecological resilience as a way of applying current understandings of complex adaptive systems to restoration for improved outcomes. Trout Unlimited Canada's Stream Rehabilitation, From Form to Function Training Program was assessed and restoration initiatives informed by the program were evaluated in terms of social-ecological resilience. The findings from this study indicate that the approach to restoration taught in the training program, along with the initiatives informed by the program, reflect principles for building resilience. Furthermore, the outcomes of the restoration initiatives informed by the program were found to be positive. These findings provide encouraging evidence in support of a new approach to restoration informed by social-ecological resilience.

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List of Abbreviations

ALHB	Asian longhorned beetle
CAQDAS	Computer assisted qualitative data analysis software
CAS	Complex adaptive systems
CVC	Credit Valley Conservation
FISRWG	Federal Interagency Stream Restoration Working Group
GRCA	Grand River Conservation Authority
MNRF	Ministry of Natural Resources and Forestry
OHT	Ontario Heritage Trust
PIT	Passive integrated transponder
REB	Research Ethics Board
RI1	Restoration Initiative One
RI2	Restoration Initiative Two
RI3	Restoration Initiative Three
SER	Society for Ecological Restoration
SES	Social-ecological systems
TUC	Trout Unlimited Canada
UCCA	Upper Credit Conservation Area

Chapter One: Introduction

Freshwater ecosystems – lakes, rivers, wetlands – provide critical ecosystem services. In addition to the tremendous benefit of the provision of freshwater for domestic, agricultural, and industrial uses, healthy freshwater ecosystems also provide important cultural, regulating, and supporting services that directly and indirectly contribute to human well-being (Aylward et al., 2005; Sabater, 2008). Lotic systems, systems of flowing water, maintain water quality, provide flood control, facilitate the processing of organic matter, nutrients, and pollutants, and offer numerous recreational opportunities (Strange et al., 1999).

Freshwater ecosystems are also among the most transformed on Earth (Carpenter et al., 2011). Lotic systems in particular have undergone significant alterations in terms of hydrology, morphology, water chemistry, temperature regime, and species presence and abundance, as a result of being the focus for human settlement (Sala et al., 2000; Lake et al., 2007). Predictions regarding population growth and land use change in coming decades, combined with the impacts of a changing climate, suggest that further alteration and greater exploitation of freshwater ecosystems is inevitable (Vörösmarty et al., 2005; Bates et al., 2008). The aforementioned alterations to, and stresses on, freshwater ecosystems influence the ability of these systems to provide the services that humans and wildlife rely on (Aylward et al., 2005).

In Canada, freshwater ecosystems, and the ecosystem services they provide, have played an integral role in shaping the development of the country and remain an important part of Canadian identity (Environment Canada, 2010). However, in line with global trends, concerns about the integrity of freshwater ecosystems in Canada are evident now and growing. Severe algal blooms in Lake Erie (IJC, 2014) and Lake Winnipeg (Environment Canada, 2011), significantly altered environmental flows and declining Atlantic salmon populations in the Saint John River (WWF-Canada, 2009), and reduced coldwater habitat in streams in the Lake Ontario basin (NPCA, 2014) are a few examples of the many mounting concerns surrounding Canada's freshwater ecosystems.

In light of the threats facing freshwater ecosystems in Canada and throughout the world, ecological restoration became, and continues to be, an important goal as it offers hope for recovery from ecosystem impairment. Ecological restoration is "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed" (Clewell & Aronson, 2013, p. 3). Ecological restoration encompasses a broad range of activities from local to regional initiatives, one-off projects to multi-year programs, volunteer efforts to large-scale multi-agency endeavours, and passive and active abiotic and biotic interventions, all with the common aim of assisting ecosystem recovery (Hobbs & Cramer, 2008; Perring et al., 2015). Societal demand for ecological restoration is growing with increasing recognition of the full extent of potential benefits associated with restoration (Gann & Lamb, 2006; Suding, 2011; Perring et al., 2015). Gann and Lamb (2006, p. 1) assert that in addition to the obvious conservation benefits, ecological restoration is unique in its ability to improve the human condition, "to renew economic opportunities, rejuvenate traditional cultural practices and refocus the aspirations of local communities”. Roberts et al. (2009, p. 555) further describe the importance of ecological restoration declaring, “our planet’s future may depend on the maturation of the young discipline of ecological restoration”.

Although undertaken with the best of intentions, attempts at ecological restoration can fail to produce intended results, or even exacerbate problems when based on oversimplified understandings of a system (Hobbs & Norton, 1996; Lake et al., 2007). Restoration projects, premised on the assumption that it is possible to create or restore an ecosystem that provides a specific set of services and functions, have mixed results (Bendor, 2009; Moilanen, 2009; Suding, 2011). In their study of 16 fish habitat compensation projects in Canada, Quigley and Harper (2006) found that 63% of the sites intended to offset harmful alteration, disruption, or destruction to fish habitat, experienced net losses in fish habitat productivity. Setting unrealistic or unfeasible restoration goals is another common reason for project failures (Suding, 2011). Changes in land use, biodiversity, and climatic conditions have made it impossible for an ecosystem to return to its previous state in terms of exact structure or composition, despite a heavy reliance on engineered solutions (Zellmer & Gunderson, 2008; Hobbs et al., 2011; Suding, 2011; Perring et al., 2015). Moreover, a fixation on treating symptoms, as opposed to causes of ecosystem degradation, has also been cited as contributing to non-recovery. As an example, in urban stream restoration, causes of eroded stream channels (e.g., flashy hydrographs resulting from increased rate and speed of runoff associated with greater areas of impervious surfaces) are often not addressed, with the consequence being project failure (Hilderbrand et al., 2005; Walsh et al., 2005).

Hilderbrand et al.’s (2005) detailed interpretation of the reasons for restoration project failures incorporates and adds to the aforementioned reasons. Common among Hilderbrand et al.’s (2005) myths of restoration is the reduction of complex systems to a point where simplified guiding principles can be applied universally with little understanding or consideration of uncertainty, surprise, interconnections, and temporal and spatial scales. Restoration based on such reductionist, steady state views of ecological systems is problematic and often leads to failures (Hilderbrand et al., 2005; Lake et al., 2007; Hobbs & Cramer, 2008; Mika et al., 2010). Hobbs and Cramer (2008) regard moving beyond the myths of restoration as being critical to the development of more effective restoration strategies. Evidently, there is a need for a shift in thinking when it comes to restoration.

Research on complex adaptive systems (CAS) has greatly improved understanding of systems, and has much to offer the science of restoration ecology. In contrast to the view that all systems, and the interactions that take place within them, are predictable and can be controlled with adequate theory, accurate observations, and appropriate inputs (Innes & Booher, 1999), CAS research describes systems in terms of complexity, uncertainty, and nonlinearity (Levin et al., 2013). Furthermore, rather than viewing systems as separate social or ecological entities, CAS research acknowledges the interconnections between these two domains and considers them coupled social-ecological systems (SES) instead. In SES, for example watersheds, the social and ecological domains are inextricably linked – what happens in one domain influences, and is influenced by, the other (Folke et al., 2005). For instance, human efforts to assist the recovery of an ecosystem will have an effect on the ecological domain and subsequently, impacts on the social domain, ideally in terms of the maintenance or restoration of valued ecosystem services.

Social-ecological resilience, as an emergent scholarly area, captures advancements made by CAS research in understanding systems (Folke, 2006), and is well positioned to inform new restoration approaches for improved outcomes. Resilience is a way of thinking about the ability of a CAS to learn, persist, change, or transform in response to perturbations (Folke, 2006; Walker & Salt, 2012). Complex SES can exist in different regimes or configurations and resilience is the “property that mediates transitions among those regimes” (Zellmer & Gunderson, 2008, p. 895). Social-ecological resilience, a specific type of resilience, stresses the interconnections or linkages between social and ecological systems, and embraces fundamental properties of CAS, including complexity, uncertainty, nonlinearity, and cross-scale interactions (Folke, 2006; Plummer, 2010).

Resilience thinking is being taken up in the field of restoration ecology, appreciating the value of thinking about CAS, not in terms of managing against change, but rather, managing for change (Zellmer & Gunderson, 2008). Recognizing that restoration can either aid in regime recovery or facilitate a shift to a new, more desirable regime, numerous scholars refer to a goal of maintaining, enhancing, or degrading resilience, in relation to a particular ecological system (see for example Allen et al., 2002; Suding et al., 2004; Palmer et al., 2005; Harris et al., 2006; Seavy et al., 2009). More recently, however, there is greater recognition of the interplay between ecological and social systems, and the need for integrated approaches to restoration (Zellmer & Gunderson, 2008; Suding, 2011). Research on resilience in restoration is just emerging, eliciting questions on how the concept may be useful to restoration practitioners (Hallett et al., 2013), what approaches to restoration best enable recovery or maintenance of a system’s resilience (Suding, 2011), and what ecosystem attributes confer resilience (Standish et al., 2014).

Evidence of the uptake of social-ecological resilience into ecological restoration theory and practice is beginning to appear. In reviewing conceptual developments in restoration ecology over the last 30 years, Perring et al. (2015, p. 3) state, “Increasingly, restoration aims to deliver functions such as ecosystem services and resilience, across scales, and has taken far greater account of the human dimension”. In Canada, Harris et al. (2012) developed, on behalf of the Prince Edward Island Watershed Alliance, a technical manual for watershed groups undertaking watershed management on the island. With its emphasis on the links between social and ecological systems, acknowledgement of complexity and uncertainty, and recognition of the importance of continuously learning and adapting, the manual provides an excellent example of how new perspectives are being incorporated into the planning and implementation of restoration initiatives. Trout Unlimited Canada’s (TUC) stream rehabilitation training program provides another example of how concepts associated with social-ecological resilience are informing ecological restoration, in this case, through a training manual and program aimed at volunteers and young professionals.

As there appears to be a shift underway towards restoration approaches informed by social-ecological resilience, evaluation of such approaches is imperative to verify whether improved outcomes are, in fact, being realized (Suding, 2011). However, meaningful evaluation of restoration project process and outcomes is rare for traditional approaches to restoration, let alone new, innovative approaches, for which evaluation guidelines are non-existent (Lake et al., 2007; Woolsey et al., 2007; Suding, 2011). Suding (2011, p. 476) urges that "without comprehensive project assessment, science will have only a limited ability to inform practice", therefore, this significant lack of evaluation regarding ecological restoration represents an important knowledge void.

1.1 Study Purpose and Objectives

This research responds to emerging questions about incorporating CAS thinking into ecological restoration, early signs of applying resilience concepts in restoration and assessing the extent to which social-ecological resilience is reflected in practice, and evaluating restoration projects in terms of process and outcomes. It explores aquatic ecosystem restoration and its evaluation in relation to social-ecological resilience. In doing so, this research provides insights into the possibility of an approach to restoration informed by the current state of knowledge on CAS and the potential for improved restoration outcomes as a result. These are timely contributions given the present and predicted state of freshwater ecosystems and the fact that restoration is increasingly being looked to as a means of mitigating human-caused ecosystem impairment (Perring et al., 2015).

The following three objectives are associated with the purpose of this research. A succinct description is provided for each objective detailing how it was addressed.

Objective One: to conceptually explore how social-ecological resilience may inform aquatic ecosystem restoration and its evaluation.

Incorporating resilience concepts into ecological restoration has been put forward as a means of moving away from restoration based on oversimplified understandings of systems. However, exactly how social-ecological resilience might be incorporated into ecological restoration is an area in need of further exploration (Suding 2011; Hallett et al., 2013). Objective One provides a direct response to this need by reviewing the ecological restoration and social-ecological resilience literature and considering how insights from social-ecological resilience may inform ecological restoration. In line with the need to bridge these areas, emphasis was placed on synthesis and the review culminated with a conceptual framework that guided the research.

Objective Two: to assess a training program for aquatic ecosystem restoration in relation to social-ecological resilience.

The Stream Rehabilitation, From Form to Function Training Program (formerly Aquatic Renewal Stream Restoration Training Program) is the unit of analysis for this study, and central to Objective Two and Three. The training program was developed over several years by a consortium of conservation organizations and individuals to address a need for a basic level of training among volunteers and young professionals undertaking stream and watershed restoration projects and programs (GRFMPIC, 2013; Imhof & FitzGibbon, 2014). The training program consists of a series of six workshops collectively intended to educate trainees on the functioning of aquatic systems, and provide training on rehabilitation planning, assessment, monitoring and implementation (TUC, 2015a). The training program is led by TUC on behalf of the consortium of partners, with certificates of completion issued through the University of Guelph (TUC, 2015a).

Guided by the framework developed in Objective One, the methodology (Chapter Three) sets out in detail the manner in which this training program was assessed in relation to social-ecological resilience. The assessment determined the extent to which the approach to ecological restoration taught in the training program reflects the principles outlined in the conceptual framework (Objective One).

Objective Three: to evaluate aquatic ecosystem restoration initiatives informed by the training program in terms of social-ecological resilience.

Evaluating restoration initiatives informed by the training program in terms of process and outcomes is imperative to understand if the restoration initiatives reflect what is taught in the training program, and whether practical applications of those concepts actually lead to positive outcomes. Data collection and analysis procedures in the evaluative component of the research are described in detail in Chapter Three.

1.2 Thesis Orientation and Organization

This research is concerned with taking knowledge of the interactions between social and natural systems and advancing the field of restoration ecology to address a contemporary sustainability challenge. The thesis purposefully bridges the social and natural sciences. It is important to acknowledge the transdisciplinary nature of the research at the outset, as the inclusion of different disciplines necessitated that the study be delimited in certain ways. Delimitations refer to choices made by a researcher in setting boundaries or parameters for a study (Mauch & Park, 2003). In the case of this research, boundaries were set to maintain an appropriate scope for this thesis while ensuring a sufficient amount of detail was achieved with regard to both social and biophysical aspects of the research. These choices and the limitations of the study are expanded upon and described in Chapter Three.

This thesis is organized into six chapters. Figure 1.1 provides an overview of the structure of the thesis, from the objectives to the conclusions, to assist readers with navigating the document. The first chapter has explained the need for this research and the purpose and objectives that drove the study. Chapter Two addresses Objective One, the conceptual portion of the research, by reviewing the literature on ecological restoration and resilience and subsequently highlighting intersection points between these two areas of scholarship. These points of conceptual intersection are explained in text and visually illustrated with a conceptual framework, which was used to guide this research. Chapter Three describes the methods utilized in carrying out the empirical portion of the research related to Objectives Two and Three. Included in this chapter are descriptions of the case study methodology, how the conceptual framework was operationalized for the assessment of the training program and the evaluation of restoration initiatives, and the data collection and treatment methods employed. The results of the training program assessment are presented in Chapter Four along with a discussion of the key findings from the assessment. Similarly, Chapter Five details the results and discusses the key findings from the evaluation of the individual restoration initiatives and the cross-case analysis. Chapter Six closes the thesis and provides a succinct summary of the key contributions from this research, as well as, recommendations for scholarship, future research and applied practice.

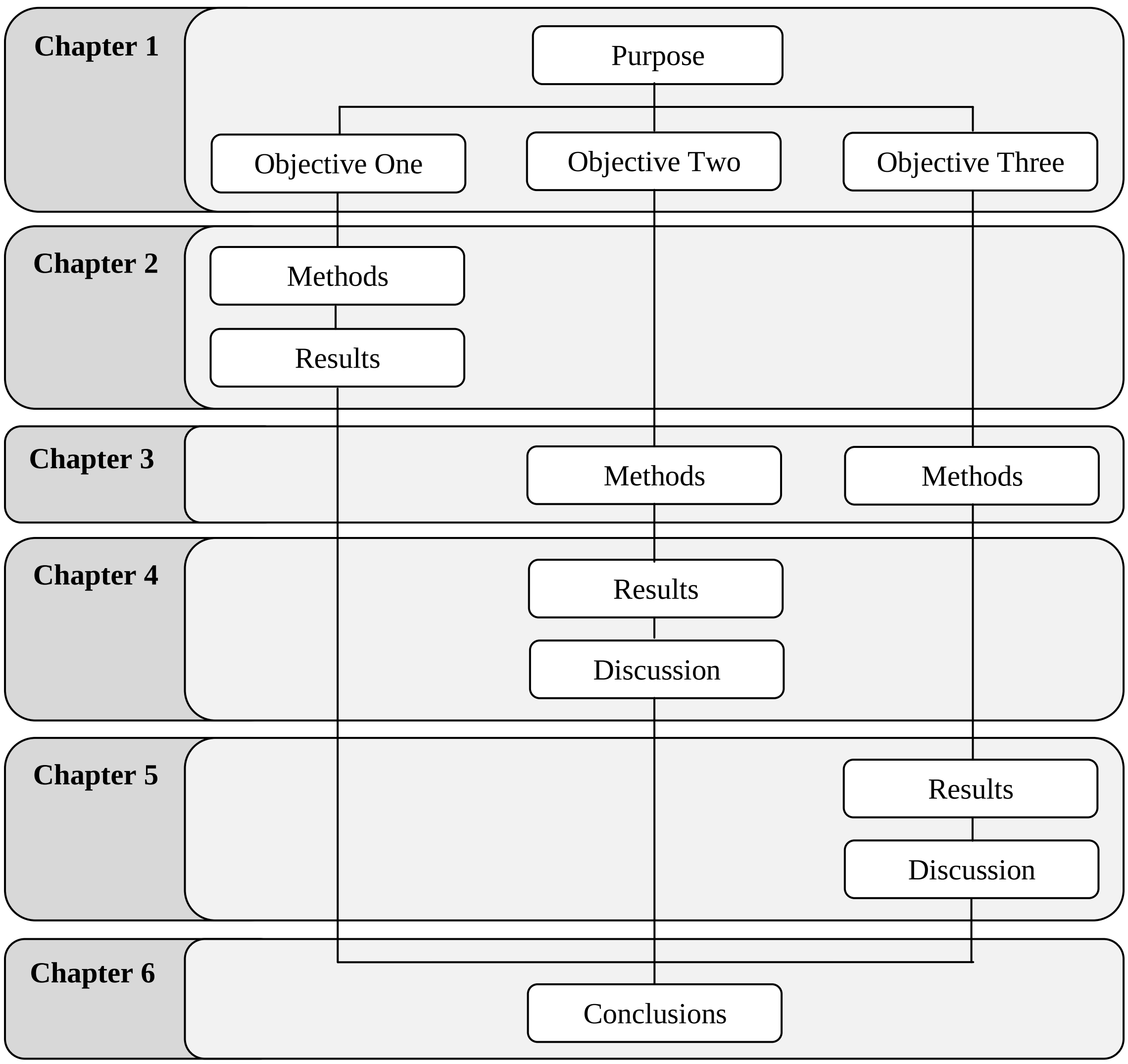

Figure 1.1 Organization of the thesis by chapter

Chapter Two: Literature Review

2.1 Introduction

The following literature review serves two purposes in line with achieving Objective One of this research – to conceptually explore how social-ecological resilience may inform aquatic ecosystem restoration and its evaluation. The first purpose is to provide an overview of two areas of scholarship, ecological restoration and resilience. The second purpose is to bridge these two areas in a novel way. It is important to recognize at the outset that vast bodies of literature exist for each area of scholarship explored in this literature review. Therefore, given the scope of this research, the literature review focuses on those areas of the literature that are most pertinent to the achievement of Objective One.

In accordance with the first purpose of this literature review, the first section begins with an exploration of the literature on the practice of ecological restoration and science of restoration ecology. Specifically, the section starts with an overview of ecological restoration in its broadest sense. As part of this overview, a few of the most prominent emerging issues and topics in restoration ecology are introduced. Two of the topics with direct relevance to this study are subsequently described in more detail, namely the evolution of perspectives in ecological restoration and the lack of, and need for, evaluating restoration initiatives. The focus of the section thereafter, narrows to consider aquatic ecosystem restoration and stream restoration more specifically. Five general phases for ecological restoration process are described based on a synthesis of several existing guidelines and are discussed in relation to stream restoration.

The next section, also in line with the first purpose of the literature review, reviews the literature on social-ecological resilience. Similar to the previous section, this section starts with a very broad overview of resilience. After introducing the related concepts of CAS and SES, the focus of the review turns to social-ecological resilience, providing a brief description of how the concept evolved from its roots in ecology. Resilience thinking is discussed next with emphasis placed on the work of Folke et al. (2003), Plummer et al. (2014b), and Biggs et al. (2012), as examples of recent efforts to summarize the current state of knowledge on resilience thinking regarding complex SES. Biggs et al.'s (2012) seven principles for building resilience in SES are highlighted as being particularly relevant to this research. Finally, resilience practice is described and attention is drawn to a number of Canadian and international examples of recent attempts to apply resilience concepts in practice.

In the final section, the two aforementioned areas of scholarship are brought together to fulfil the second purpose of the literature review and achieve Objective One. The synthesis begins with a summary of the major issues described in the ecological restoration section, followed by a review of the key points discussed in the resilience section. The conceptual intersection points between these two bodies of knowledge are subsequently explained and presented visually in a conceptual framework. The conceptual framework is the guide for this study and is referred to at all stages of the research.

2.2 Ecological Restoration

2.1.1 Overview

At a time when human activities are affecting the functioning of the Earth system and threatening its resilience (Steffen et al., 2015), ecological restoration offers hope for recovery from human-caused ecosystem impairment (Palmer et al., 2006; Egan et al., 2011). However, ecological restoration is not a new concept. Humans have always modified the environment in some way to meet their needs (Mann, 2005; Chiras, 2014), and in some cases, tended lands to ensure those needs continued to be met into the future (Palmer et al., 2006). As such, it is generally accepted that restoration in some form has taken place for centuries (Sarr et al., 2004; Palmer et al., 2006; Jordan & Lubick, 2011). Ecological restoration that moves beyond repairing selected features of a system to restoring an ecosystem as a whole, termed ecocentric restoration by Jordan and Lubick (2011), is a more recent phenomenon. Allison (2012) suggests that modern forms of ecological restoration began in the first half of the twentieth century with two parallel initiatives – prairie restoration in the American Midwest and mine reclamation in Europe and North America. Since then, many different types of restoration have been carried out in countries across the globe.

With restoration initiatives and research taking place around the world but no real way for these efforts to support or build on each other, the Society for Ecological Restoration (SER) was founded in 1987 to bring otherwise disconnected restoration researchers and practitioners together (SER, 2016b). The goals and objectives of SER include, but are not limited to, promoting research, facilitating communication among restorationsists, and contributing to discussions of public policy in matters having to do with restoration (SER, 2016b).

Ecological restoration, as defined by SER (SER, 2004, p. 3), is “the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed”. More specifically, SER (2004, p. 1) qualifies ecological restoration as “an intentional activity that initiates or accelerates the recovery of an ecosystem with respect to its health, integrity and sustainability”. The SER definition is the most widely accepted definition of ecological restoration (Harris et al., 2006) and will be used for this research.

Rehabilitation is a concept closely related to restoration and described by Clewell and Aronson (2013, p. 203) as the “reparation of ecosystem processes, productivity, and services rendered without regard to achieving the fullest possible reestablishment of pre-existing biota in terms of its species composition and community structure”. Where complete restoration of a degraded ecosystem is unrealistic or would be extremely expensive, rehabilitation aims to improve the state of the ecosystem without the expectation of a return to its original state or as healthy a state as if it had been fully restored (Imhof et al., 1996; Bradshaw, 1997; Kauffman et al., 1997; SER, 2004; Choi, 2007). For example, in urban areas, reconnecting a channel with its former floodplain is often impossible but improvements can be made in other areas to enhance the state of the ecosystem. Furthermore, rehabilitation differs from restoration in that it is undertaken with the assumption that an ecosystem's former functionality can be reinstated with species other than those that occurred in the past through substitution (SER, 2004; Clewell & Aronson, 2013).

Choi (2007) argues that presently, almost all actions of restoration fall under the definition of rehabilitation and that in most situations, rehabilitation is the best option as much of the damages in the environment are irreversible. Clewell and Aronson (2013) also speak to the overlap between the concepts of restoration and rehabilitation asserting that rehabilitation with the aim of re-establishing historic continuity qualifies as restoration. This section refers to restoration but acknowledges that rehabilitation is, in many situations, a more realistic or attainable goal for improving the state of a degraded ecosystem.

Ecological restoration encompasses all types of terrestrial and aquatic ecosystems. The latter is the focus of this research and will be discussed in greater detail in section 2.2.4. Ecological restoration initiatives can take many different forms and involve varying degrees of effort (Hobbs & Norton, 1996), from prescribed natural regeneration involving the removal of sources of disturbance that cause impairment and protecting the project site (see for example Shono et al., 2007), to complete reconstruction in which the biophysical environment is manipulated in some way at all stages of recovery (Clewell & McDonald, 2009; Clewell & Aronson, 2013). Common across this continuum of restoration activities is the intent to assist ecosystem recovery (Clewell & Aronson, 2013).

The goal or goals of ecological restoration can vary significantly based on the definition being considered (see for example Risser, 1999; Falk et al., 1996; Kershner, 1997). In keeping with the SER (2004) definition of ecological restoration, the overarching goal is to return an ecosystem to its historic ecological trajectory and reinstate ecological wholeness (Clewell & Aronson, 2013). The historic ecological trajectory of an ecosystem is defined as "a record of the sequential changes in expression that an ecosystem undergoes through time" (Clewell & Aronson, 2013, p. 4). When an ecosystem is impaired, its historic trajectory is said to be interrupted (Clewell & Aronson, 2013). Accordingly, ecological restoration aims to restore continuity in terms of the broad structural aspects of the pre-impairment ecosystem, not a particular historic expression of that ecosystem (Clewell & Aronson, 2013). Restoration of historic continuity can be facilitated using an ecological reference consisting of one or more reference sites, or their ecological descriptions that determine the intended characteristics of a restored ecosystem (White & Walker, 1997; Moore et al., 1999; SER, 2004; Clewell & Aronson, 2013). An ecosystem is considered to have undergone holistic restoration and exhibit 'wholeness' if it possesses eleven attributes described by Clewell and Aronson (2013) pertaining to species composition, community structure, flows and exchanges of organisms and materials, ecological functionality, historic continuity, ecological complexity, the capacity for self-organization, resilience, and self-sustainability, and biosphere support.

2.1.1.1 Emerging Issues

Although the practice of ecological restoration extends much further back in time, the science of restoration ecology only truly began to take shape in the 1990s (Pickett & Parker, 1994; White, 1996; Palmer et al., 1997; Young et al., 2005; Egan et al., 2011). While great strides have been made, the science of restoration ecology is still relatively young (Young et al., 2005; Hobbs et al., 2011) and as it matures, issues emerge and are debated in the literature. The reality of climate change and novel ecosystems (Harris et al., 2006; Dunwiddie et al., 2009; Jackson & Hobbs, 2009; Allison, 2012; Clewell & Aronson, 2013), the need for new perspectives on ecological restoration that appreciate interconnections between the social and biophysical domains (Noss et al., 2006; Choi, 2007; Zellmer & Gunderson, 2008; Suding, 2011; Naiman, 2013), and the significant lack of project evaluation (Kondolf & Micheli, 1995; Lake et al., 2007; Woolsey et al., 2007; Suding, 2011; Wortley et al., 2013) are currently three of the most pressing and widely debated examples in restoration ecology. The importance of these emerging issues is confirmed by their prominence in recent SER world conferences on ecological restoration (SER, 2011; SER 2013). Each emerging issue is briefly introduced in this review.

There is disagreement among scholars over what climate change means for ecosystems and consequently, ecological restoration (Harris et al., 2006; Allison, 2012; Clewell & Aronson, 2013; Dooling, 2015; Perring et al., 2015). Much of this debate is focused on the concept of novel ecosystems, defined by Hobbs et al. (2009, p. 601) as ecosystems in which “the species composition and/or function have been completely transformed from the historic system”. Scholars overwhelmingly agree that novelty in ecosystems is not an entirely new concept (Hobbs et al., 2006; Jackson & Hobbs, 2009; Allison, 2012; Clewell & Aronson, 2013; Perring et al., 2013), the concern is the accelerated rate and scale of changes being experienced (Allison, 2012). There is less agreement, however, on the role of ecological restoration in relation to these novel ecosystems (Perring et al., 2015). Clewell and Aronson (2013, p. 244) clearly articulate their position on the subject cautioning that many authors have overlooked or underestimated collective capacity to address the issue and assume there is no choice but to “surrender and accept novel ecosystems as substitutes and the new norm”. The authors go on to argue that many so-called novel ecosystems are actually impaired ecosystems that can be returned to their historic ecological trajectory via ecological restoration (Clewell & Aronson, 2013). The concept of novel ecosystems will remain a debated issue into the future (Perring et al., 2015).

Awareness is rapidly growing in the field of ecological restoration regarding the importance of planning projects with consideration of the interconnections between, and constraints imposed by, both the social and biophysical domains (Noss et al., 2006; Choi, 2007; Zellmer & Gunderson, 2008; Egan et al., 2011; Suding, 2011; Naiman, 2013). This interplay is acknowledged by Bliss and Fischer (2011, p. 144) who state that ecological restoration is a value-driven social process requiring “not only a firm foundation of sound ecological science but also a critical understanding of the dynamic interactions and relationships among people and between people and the landscapes they inhabit”.

Statements such as Bliss and Fischer's (2011) suggest that perspectives are evolving from a purely ecological focus to include social considerations as well. However, this shift in thinking is not always reflected in practice (Wortley et al., 2013). Therefore, more attention directed at applying these ideas to ecological restoration on the ground is necessary (Suding, 2011; Naiman, 2013).

Evaluation provides important information about the "merit(s) or worth of an act" (Plummer & Armitage, 2007, p. 63), yet far too often it is overlooked in natural resource management broadly (Rogers & Biggs, 1999; Plummer & Armitage, 2007), and ecological restoration more specifically (Lake et al., 2007; Woolsey et al., 2007; Suding, 2011). Considering that restoration ecology is purported to be a litmus test for the applicability of ecological theories in practice (Bradshaw, 1983; Choi, 2007; Perring et al., 2015), relatively little is actually known about the success or failure of initiatives (Palmer & Allan, 2006; Wortley et al., 2013). Without adequate monitoring and subsequent evaluation of restoration initiative outcomes, future projects cannot benefit from past experiences of what has and has not worked (Palmer et al., 2005; Bernhardt & Palmer, 2011; Suding, 2011). Many scholars have flagged the need for evaluation to improve the science and practice of ecological restoration (Pickett & Parker, 1994; Kondolf & Micheli, 1995; Bash & Ryan, 2002; DellaSala et al., 2003; Bernhardt et al., 2007; Suding, 2011; Wortley et al., 2013). Evidently, evaluation has an important role to play in ecological restoration.

As the first objective of this research concerns conceptually exploring how new perspectives may inform aquatic ecosystem restoration and its evaluation, the following two sections pick up on, and describe in more detail, the evolution of perspectives in ecological restoration and the need for evaluation, before focusing in on aquatic ecosystem restoration more specifically.

2.2.2 Evolution of Perspectives

Perspectives on ecological restoration are not static. Much has changed, and continues to change, in terms of how ecosystems are understood, which activities are considered under the term restoration, how goals are defined, and how success is measured (Perring et al., 2015). This evolution of perspectives is to be expected as restoration ecology matures as a science and as knowledge of ecosystem dynamics advances (Suding, 2011). The changes in perspectives related to ecological restoration over the past couple of decades have not progressed in a neat, chronological order with new perspectives replacing old perspectives. Rather, new perspectives have been proposed and discussed in the literature alongside older perspectives. Some perspectives, for example, the need for ecological restoration to be understood and undertaken as an integrated solution involving both social and ecological considerations, have been persistent topics of discussion for close to two decades (see for example Higgs, 1994; Wyant et al., 1995; Cairns & Heckman, 1996; White, 1996). Three broad perspectives are described here.

The first perspective on ecological restoration described here is that of restoring an ecosystem with the aim of recovering a historic state that existed before major human disturbances. In North America, this historic state is typically associated with the period of time prior to European settlement (i.e., 200-300 years ago) (Choi, 2007), although the pre-European landscape was likely already shaped by human influences. By emulating historic conditions, this perspective on restoration assumes that an ecosystem will return to a more ‘natural’ or ‘pristine’ state, functioning in a manner similar to its pre-impairment condition (Hobbs & Harris, 2001; Suding et al., 2004; Hilderbrand et al., 2005; Hobbs & Cramer, 2008; Perring et al., 2015). This perspective is based on the notion that it is possible to replicate a specific combination of ecosystem conditions (Hobbs & Harris, 2001; Hobbs & Cramer, 2008). As understanding of complex systems has improved, it has become increasingly apparent that returning to a specific historic state or ecosystem expression is no longer viable (Hilderbrand et al., 2005; Harris et al., 2006; Jackson & Hobbs, 2009; Allison, 2012). Scholars have been writing about the need to abandon this backwards looking perspective on restoration since the early 1990s and have continued to do so more recently (Pickett & Parker, 1994; Wohl, 2001; Hilderbrand et al., 2005; Choi, 2007; Jackson & Hobbs, 2009). The realities of unpredictable successional processes (Pickett & Parker, 1994; Hobbs & Norton, 1996; Suding et al., 2004; Choi, 2007), multiple alternative stable states (Pickett & Parker, 1994; Young et al., 2001; Suding & Gross, 2006; Choi, 2007; Jackson & Hobbs, 2009), nonlinear and threshold responses to natural and anthropogenic disturbances (Hobbs & Norton, 1996; Lindenmayer et al., 2008; Suding & Hobbs, 2009; Perring et al., 2015), dynamic ecosystem processes (Pickett & Parker, 1994; Hobbs & Harris, 2001; Choi, 2007; Suding, 2011), and the ecological legacies left by human activities (Hobbs & Harris, 2001; Jackson & Hobbs, 2009; Allison, 2012) all support a shift away from this perspective.

As opposed to attempting to restore a historic ecosystem, an alternative perspective gives greater consideration to the dynamic nature of ecosystems and acknowledges complexity (Hobbs & Norton, 1996; Choi, 2007; Suding, 2011; Perring et al., 2015). Proposed aims of ecological restoration informed by this alternative perspective are all closely related and include restoration of ecosystem functions and/or processes (Harris et al., 2006; Hobbs & Cramer, 2008; Beechie et al., 2010; Perring et al., 2015), desirable ecological goods and services (Bullock et al., 2011; Nellemann & Corcoran, 2010; Suding, 2011; Perring et al., 2015), ecological integrity (Jungwirth et al., 2002; DellaSala et al., 2003; Parks Canada, 2008), and resilience (Carpenter & Cottingham, 1997; Zellmer & Gunderson, 2008; Suding, 2011; Wilson & Browning, 2012; Perring et al., 2015). Each of these variations of the same general perspective share many commonalities and are, therefore, discussed here as one broad perspective contrasting the aforementioned approach of attempting to return an ecosystem to a historic state. This alternative perspective, referred to as ‘Restoration v2.0’ by Perring et al. (2015), supports the view that ecological restoration is a very complex endeavour and should involve the consideration of an ecosystem’s unique past, its specific spatial setting with consideration of larger and smaller scales, and current and future drivers of change (Pickett & Parker, 1994; Hobbs & Norton, 1996; Zellmer & Gunderson, 2008; Jackson & Hobbs, 2009; Suding et al., 2015). Furthermore, this perspective operates on the assumption that change is inevitable and that ecological restoration must work with, rather than against change including emerging conditions (Allen & Hoekstra, 1992; Zellmer & Gunderson, 2008; Jackson & Hobbs, 2009).

Finally, an increasing number of scholars have recently expressed the need to take social considerations into account when undertaking ecological restoration (see for example Choi, 2007; Zellmer & Gunderson, 2008; Bliss & Fischer, 2011; Naiman, 2013; Abelson et al., 2015; Perring et al., 2015). This perspective reflects the recognition that human activities have arguably had an impact on every part of the world and that ecosystems are continuously evolving in response to such external influences, as well as, endogenous processes (Vitousek et al., 1997; Sanderson et al., 2002; Clewell & Aronson, 2013). The perception of humans being external to, or removed from, ecosystems is replaced with the understanding that social and ecological domains interact and humans are simply one species within the larger integrated system (Egan et al., 2011). In order to be successful, it is important from this perspective for ecological restoration to be considered within its social context. This includes, but is not limited to, consideration of the cultural and economic situations, laws, policies, institutions, and the values and interests of individuals (Parks Canada, 2008; Zellmer & Gunderson, 2008; Egan et al., 2011; Nilsson & Aradóttir, 2013). In support of an integrated perspective on ecological restoration, Zellmer and Gunderson (2008) provide the Everglades as an example of a case in which substandard project outcomes have been observed as a result of considering the ecological domain separate from the social, legal, and political domains.

2.2.3 Evaluation

Evaluation is a critical step in the process of ecological restoration. It is crucial for a variety of reasons for project managers and other restoration practitioners, funders, policy makers, other stakeholders, and the general public to have a sense of how successful restoration initiatives are in achieving their goals and objectives (Rogers & Biggs, 1999; Palmer et al., 2005; Clewell & Aronson, 2013; Wortley et al., 2013). Most importantly, insights regarding ecological restoration successes and failures are important for informing future initiatives and the science of restoration ecology (Kondolf & Micheli, 1995; Palmer et al. 2005; Woolsey et al., 2007; Nilsson & Aradóttir, 2013).

Evaluation of a restoration initiative should reflect the specific goals and objectives of that initiative (SER, 2004; Clewell & Aronson, 2013), therefore, the exact form that evaluation takes will differ from one project to another. Nevertheless, SER (2004) has proposed a list of nine attributes of a successfully restored ecosystem to help guide evaluation. The attributes can be considered to fall within one of three categories including vegetation structure, species diversity and abundance, and ecological processes (SER, 2004; Ruiz-Jaen & Aide, 2005; Wortley et al., 2013). SER (2004) recommends incorporating additional social or ecological attributes according to the identified goals of the initiative. According to the SER (2004) *Primer on Ecological Restoration*, a system is not required to fully express all nine of the attributes to be deemed restored. Rather, the attributes should “demonstrate an appropriate trajectory of ecosystem development towards the intended goals or reference” (SER, 2004, p. 3). More recently, Clewell and Aronson (2013, p. 89) put forth a set of revised attributes characterizing successfully restored ecosystems –four directly attainable attributes that manifest in response to biophysical interventions and seven indirectly attainable attributes that “appear or emerge on account of interactions of organisms with each other and their abiotic environment”.

Other evaluation guidelines are more specific and apply to the restoration of particular ecosystems. For example, Palmer et al. (2005) suggest five criteria for measuring the success of river restoration, primarily from an ecological perspective. The authors offer example guidelines and possible indicators that can be used to evaluate each criterion but emphasize that the exact indicators selected, and the methods used to measure them, must be tailored to the ecological goals of the restoration initiative (Palmer et al., 2005). The five criteria for ecological success outlined by Palmer et al. (2005) include the following: the design of the project is based on a specified guiding image; the river’s ecological condition is measurably improved; resilience of the ecosystem is enhanced; no lasting harm is done; and some level of pre- and post-restoration assessment is conducted and the resulting information is shared.

Despite the importance of evaluation, and the presence of at least a few well-cited guidelines (see for example Ewel, 1987; Hobbs & Norton, 1996; SER, 2004; Palmer et al., 2005), the need for more evaluation, and evaluation that acknowledges both ecological and social considerations, has been identified in the scholarly literature (Kondolf & Micheli, 1995; Lake et al., 2007; Woolsey et al., 2007; Aronson et al., 2010; Suding, 2011; Wortley et al., 2013; Perring et al., 2015). Complementing previous reviews by Ruiz-Jaen and Aide (2005) and Aronson et al. (2010), Wortley et al. (2013) conducted a review of the ecological restoration literature looking at empirical assessments of terrestrial restoration initiatives. Although their research uncovered that the number of papers empirically evaluating terrestrial restoration initiatives had increased since similar reviews in 2005 and 2010, very few papers were found which assessed socioeconomic attributes of restoration (Wortley et al., 2013). Ecological attributes stood out as the most common measures used for post-project assessments, with 94% of the identified studies measuring only ecological attributes and no social or economic attributes (Wortley et al., 2013).

Several reasons for why so little project evaluation is documented in the ecological restoration literature, and what makes evaluation challenging, have been proposed. These reasons include the fact that ecological restoration, as a discipline, is relatively young when considering the length of time required for the recovery of ecological processes (Kondolf, 1995; Choi, 2004; Wortley et al., 2013), poorly defined targets (Bernhardt et al., 2007; Wortley et al., 2013), limited monitoring or poor quality monitoring (Kondolf, 1995; Suding, 2011; Wortley et al., 2013), limited access to monitoring data (Suding, 2011), budgetary restrictions (Kondolf, 1995; Federal Interagency Stream Restoration Working Group (FISRWG), 2001), difficulties associated with shifting baselines (Woolsey et al., 2007; Suding, 2011), and a lack of consensus on what characterizes successful restoration and how best to measure it (Hobbs & Norton, 1996; Palmer et al., 2005; Woolsey et al., 2007; Suding, 2011).

2.2.4 Aquatic Ecosystem Restoration

Although ecological restoration is applicable to both terrestrial and aquatic ecosystems, the focus of this research is aquatic ecosystems. An aquatic ecosystem is defined as "a group of interacting organisms dependent on one another and their water environment for nutrients (e.g., nitrogen and phosphorus) and shelter" (Environment Canada, 2010, online). Aquatic ecosystems can be divided into two groups based on the presence of dissolved compounds, namely salts, in the water (Krohne, 1998). Aquatic ecosystems with saline waters such as oceans, salt marshes, lagoons, mangroves, and estuaries are termed marine ecosystems, while aquatic ecosystems with a very low salt content are considered freshwater ecosystems (Krohne, 1998). Freshwater ecosystems can be further divided into lentic and lotic ecosystems (Krohne, 1998; Jørgensen et al., 2013). Lentic ecosystems, including lakes and ponds, are characterised by standing water (Spellman, 1996). Conversely, lotic ecosystems are systems of flowing or running water and include springs, creeks, streams, and rivers (Giller & Malmqvist, 1998; Jørgensen et al., 2013). This research looks specifically at the restoration of stream and river ecosystems.

There are numerous ways to define the terms stream and river, and their usage varies by geographic location (Riley, 1998; FISRWG, 2001; Gordon et al., 2004; Fisher & Sponseller, 2010; Jørgensen et al., 2013). The terms are often used interchangeably to refer to flowing waters of various widths and depths (Gordon et al., 2004; Fisher & Sponseller, 2010). For the purpose of this research, the term stream is used to refer to all flowing bodies of water confined by a bed and banks.

Stream ecosystems are complex, dynamic systems that interact with, and evolve in response to, surrounding ecosystems (FISRWG, 2001). Stream ecosystems play a critical role in the hydrologic cycle and are instrumental in the movement and cycling of nutrients and sediment (Daigle & Havinga, 1996; FISRWG, 2001). Moreover, they provide habitat and a source of food and water for aquatic and terrestrial species (Daigle & Havinga, 1996). Humans also receive considerable benefits from healthy streams in the form of ecosystem goods and services (Riley, 1998; FISRWG, 2001; Aylward et al., 2005). Generally speaking, healthy streams are dynamic, self-regulating systems that function within natural ranges of flow, sediment movement, temperature regime, water chemistry, and other key properties (Ontario Ministry of Natural Resources (OMNR), 1994; Daigle & Havinga, 1996; FISRWG, 2001; Gordon et al., 2004). Exactly what those natural ranges are varies depending on the geographic location of the stream and location of the stream within its watershed (Vannote et al., 1980; FISRWG, 2001).

Humans have a long history of manipulating streams for a variety of purposes including waste disposal, irrigation, transportation, hydropower, logging, mining, flood control, and recreation (Giller & Malmqvist, 1998; FISRWG, 2001; Harman et al., 2012; Jørgensen et al., 2013). Over time these human activities have compromised the ability of streams to self-regulate, which in turn has many social and ecological consequences including degradation of water quality, negative impacts on human health, decreased water storage and conveyance capacity, loss of habitat for fish and wildlife, and decreased recreational and aesthetic value (National Research Council, 1992; OMNR, 1994; FISRWG, 2001). In keeping with the definition of ecological restoration provided in section 2.2.1, the intention of stream restoration is to identify causes and symptoms of impairment such as those previously mentioned, and assist the recovery of a stream ecosystem's health, integrity, and sustainability in accordance with its historic ecological trajectory (FISRWG, 2001; SER, 2004).

Streams can be considered at several different spatial scales from local to broad (Imhof et al., 1996; FISRWG, 2001; OMNR and Watershed Science Centre, 2002). For example, the FISRWG (2001) describes streams in terms of the stream reach, stream, stream corridor, landscape, and region scale. Alternatively, in their work on characterizing watershed ecosystems for fish habitat, Imhof et al. (1996) describe five system levels including habitat element, site, reach, subwatershed, and watershed. For this study, the discussion of ecological restoration focuses primarily on the scale corresponding with the FISRWG's (2001) stream corridor scale. A stream corridor is an area where the energy of water movement is focused from diffused runoff from the rest of the watershed (FISRWG, 2001). Similar to Imhof et al.'s (1996) reach scale consisting of the stream, riparian zone, and floodplain, the stream corridor is comprised of a channel, floodplain, and transitional upland fringe (FISRWG, 2001; Matlock & Morgan, 2011). Restoration projects often take place at the stream corridor scale with a great deal of consideration also given to the scales above and below particularly during the planning stages (FISRWG, 2001; OMNR and Watershed Science Centre, 2002; Shields et al., 2003a; Perring et al., 2015). Since restoration of even a small reach of a stream can be resource intensive, it is often suggested that stream corridor restoration initiatives are planned as part of a larger, longer-term watershed restoration program or management plan (Daigle & Havinga, 1996; Harman et al., 2012; The Environmental Law Institute & The Nature Conservancy, 2014).

From planning through to implementation, after care, and evaluation, the ecological restoration process can be scaled to fit the needs of the initiative and the resources of those planning and executing it. A number of general guidelines or stepwise procedures have been developed that are broad enough to apply to any type of restoration initiative. Examples of these procedures include the SER guidelines grouped into six phases of project work (Clewell et al., 2005), Daigle and Havinga's (1996) nine steps to site-level planning and implementation, Parks Canada's (2008) framework for planning and implementation of ecological restoration in protected natural areas, and Rieger et al.'s (2014) four-phase framework for ecological restoration and accompanying project development process. Sets of guidelines have also been created specifically for planning and implementation of stream restoration initiatives. The OMNR (1994) nine steps of designing a natural channel, the FISRWG (2001) steps of restoration plan development, the United States Department of Agriculture Natural Resources Conservation Service (2007) stream restoration design process, and the OMNR and Watershed Science Centre (2002) framework for stream corridor management and design are several examples. There are many commonalities between the stream restoration specific sets of guidelines and the general guidelines but the former provide much more detail in terms of considerations specific to working with stream corridors and the scales above and below.

Some elements common among the aforementioned sets of guidelines include problem identification and definition, development of project goals and objectives, designing a plan and formulating alternatives, installation or implementation, and monitoring and evaluation. Although these steps or phases may have different names, be listed in different orders or grouped together with other steps, they serve roughly the same purpose across sets of guidelines. Each step is briefly described below in very general terms due to the fact that all aspects of stream corridor restoration vary based on the specific context of the initiative being considered.

2.2.4.1 Problem Identification

Problem identification is simultaneously considered one of the most important and most challenging steps in the development of a stream corridor restoration plan (Daigle & Havinga, 1996; FISRWG, 2001). The OMNR and Watershed Science Centre (2002, p. 7-1) describes a problem in the context of stream corridor restoration as "a perception that the stream is not operating as it should be". What makes problem identification so difficult is the fact that stream corridors are dynamic systems exhibiting natural changes. Distinguishing between changes that are a natural, healthy part of stream corridor functioning and those that indicate unhealthy instability, degradation, or aggradation, is not always a simple task (Daigle & Havinga, 1996). Problems can manifest as excessive erosion or sedimentation, changes in aesthetic qualities, lack of diversity in stream bank vegetation, dying, diseased, or absent aquatic species, and prolonged periods of flooding or drought at inappropriate times (Daigle & Havinga, 1996; OMNR and Watershed Science Centre, 2002). A perceived problem can be identified by any member of a community, however, further definition of that problem and the actions that follow are typically led by an interest group, municipality, or major owner (OMNR and Watershed Science Centre, 2002).

2.2.4.2 Defining Goals and Objectives

The definition of project goals and objectives is typically regarded as the single most important step in planning a stream corridor restoration initiative (Ehrenfeld, 2000). In addition to setting the long-term expectations for what an initiative is intended to accomplish, the goals and objectives guide the remainder of the planning process and determine monitoring needs and project evaluation (Daigle & Havinga, 1996; Ehrenfeld, 2000; Perring et al., 2015). No universally optimal way of specifying goals has been indicated in the literature on stream corridor restoration (Ehrenfeld, 2000). Nevertheless, the FISRWG (2001) outlines the following four components of a goal and objective development process: define the desired future condition; identify scale considerations; identify both technical and nontechnical restoration constraints including financial, political, legal, and regulatory constraints; and define goals and objectives. According to this model, project goals should be an integration of the desired future stream corridor condition based on an ecological reference and social, political, and economic values (FISRWG, 2001). Complementing project goals are the project objectives. Objectives identify the short and long term activities that are required to achieve the specified goal or goals (Daigle & Havinga, 1996). They should express which conditions of the impaired stream corridor will be moved towards the predetermined desired conditions expressed by the reference site or sites (FISRWG, 2001). As such, objectives serve as the basis for monitoring and evaluating the success of an initiative (SER, 2004).

2.2.4.3 Designing a Restoration Plan

With the identified problem or problems and the goals of the project guiding the process, alternative solutions should be acknowledged and assessed in terms of feasibility, cost-effectiveness, environmental impact, and social acceptability (FISRWG, 2001). Daigle and Havinga (1996) distinguish between two approaches to restoration, indirect and direct. In this classification, indirect stream restoration involves activities that reduce causes of degradation in stream corridors, as well as activities that minimize the resulting impacts (Daigle & Havinga, 1996). Direct restoration is more apparent at the site-level and includes structural changes, bioengineering, and in-stream enhancements (Daigle & Havinga, 1996). Indirect restoration activities are intended to make direct restoration at the site-level more effective (Daigle & Havinga, 1996). The FISRWG (2001) provides an alternative classification for stream corridor restoration, suggesting three basic approaches. First, non-intervention and undisturbed recovery describes a hands-off approach in which active restoration is not necessary due to the rapid natural recovery of the stream corridor (FISRWG, 2001). Second, partial intervention for assisted recovery, as the name suggests, involves minimally invasive actions to facilitate natural processes that are already occurring as part of the system's recovery (FISRWG, 2001). Finally, substantial intervention for managed recovery entails active restoration measures to recover desired functions that are believed to be beyond the stream ecosystem's natural restorative capacity (FISRWG, 2001). This type of intervention may be required when a threshold has been crossed. As a general rule, the least intrusive approach to restoration is preferable (Shields et al., 2003b).

2.2.4.4 Implementation

Before any of the hands-on, in-stream work begins, a great deal of planning is required to improve the likelihood of successful project implementation. For example, an appropriate work schedule must be developed, sources of funding need to be secured, permits may be required, materials and equipment need to be sourced, site preparation such as dewatering and fish rescue may need to be arranged, contractors need to be hired and volunteers need to be coordinated and supervised (FISRWG, 2001). Furthermore, stream corridor restoration projects, especially large initiatives, are often planned by an interdisciplinary team led by a project manager (FISRWG, 2001). Careful coordination of all of the different parts of the team is critical throughout the life of the project including the implementation phase. Even small-scale initiatives require a considerable amount of planning and scheduling to ensure successful implementation.
Installation or implementation may involve any number of the many restoration techniques and practices available to stream restoration practitioners. A sample of the categorizations of stream restoration techniques and practices along with specific examples is provided in Table 2.1. Table 2.1 is not an exhaustive list of categorizations and only touches on a few of the many specific techniques and practices available.

Table 2.1 Categorizations of stream restoration techniques and practices

Source	Categories of Techniques/Practices	Examples
US EPA (1995)	• In-stream techniques • Riparian techniques • Upland/watershed techniques	• Channel realignment • Restrictive fencing • Agricultural BMPs

Daigle and Havinga (1996)	• Structural changes
	• Bionengineering or plantings
	• In-stream enhancements
	  ○ Bed enhancements
	  ○ Habitat structures
	  ○ Flow control devices
	  ○ Organic debris
		• Reconnecting stranded wetlands
		• Brush mats
		
		• Large boulders
		• Lunkers
		• Channel deflectors
		• Logs and branches

Brown (2000)	• Bank protection • Grade control • Flow deflection/concentration • Bank stabilization/bioengineering	• Rootwads • Rock vortex weirs • Rock and log vanes • Live fascines
FISRWG (2001)	• In-stream practices • Streambank treatment • Water management • Channel reconstruction • Stream corridor measures • Watershed management practices	• Fish passages • Live cribwalls • Sediment basins • Stream meander restoration • Riparian forest buffers • Streamflow temperature management
NOAA (n.d.)	• Channel restoration • Channel structural complexity • Bank stabilization • Riparian & wetland planting/seeding • Dam removals • Fishways • Culvert removal or replacement	• Mid-channel deflectors • Addition of large woody debris • Coir fiber logs • Vegetated gabions • Partial dam removal or breach • Roughened ramps • Natural substrate culvert

2.2.4.5 Monitoring and Evaluation

Monitoring is an essential aspect of stream corridor restoration before, during, and after implementation. Baseline monitoring efforts, prior to initiating project design, are instrumental in identifying current conditions and the actions required to ameliorate deficiencies in stream corridor functioning (FISRWG, 2001). During implementation, monitoring can alert the project manager to issues such as improper or inadequate sediment control and vandalism. Following implementation, monitoring becomes critical in assessing the response of the stream corridor to the restoration activities and documenting progress made towards objectives.

Monitoring data are used to evaluate whether or not the restoration effort has, or is on the path to, achieving the predefined project goals and objectives (FISRWG, 2001). The parameters used to evaluate a restoration initiative are largely context dependent but can be generally considered under the very broad categories of physical, biological, and chemical parameters, as well as human interest factors (FISRWG, 2001). Furthermore, ongoing monitoring of restoration initiatives is strongly advised as part of an adaptive management approach (FISRWG, 2001; OMNR and Watershed Science Centre, 2002).

Even the most carefully planned and executed projects will likely require midcourse correction or follow-up actions (FISRWG, 2001). The evaluation of outcomes should inform future work leading to an iterative process.

2.3 Resilience

2.3.1 Overview

In exploring the evolution of perspectives related to ecological restoration in section 2.2.2, several points were raised about the need to shift the way ecosystems are understood in order to reflect the inherent complexity of these systems. The emergence of scholarship addressing CAS and SES coincide with these needs.

CAS research, as described by Levin (1998, p. 432), pertains to the study of how "complicated structures and patterns of interaction can arise from disorder through simple but powerful rules that guide change". Economies, organisms, ecosystems, the biosphere, and human societies are all considered CAS based on the fact that interactions among components of each of these systems leads to the emergence of system properties at a higher scale, which then feedback and influence subsequent interactions among system components (Levin, 1998). Holland (1995) identified four basic properties of a CAS – aggregation, nonlinearity, diversity, and flows. Aggregation refers to the grouping of individuals or basic elements of a system into, for example, populations, species, and functional groups. Furthermore, Holland (1995) explains that aggregation relates to the formation of patterns and hierarchies among these groupings as a result of self-organization, which then has an influence on further development of the system. Nonlinearity describes how the important role of chance events in CAS means that there is considerable potential for alternative developmental pathways to emerge (Holland, 1995). A consequence of nonlinearity is path dependency, the idea that as a system evolves the 'local rules of interaction' change in response to previous events (Holland, 1995). Moreover, nonlinearity and path dependency introduce the idea that a system has alternate stable states and can exhibit threshold behaviour. Diversity refers to differences or variety at, above, and below the species level. Finally, flows are discussed by Holland (1995) in terms of being the interconnections between the parts of a system, transforming otherwise disconnected parts into a connected whole. Examples of flows include the flow of energy, nutrients, and information. Holland's (1995) work is just one example of the many attempts at categorizing and describing the properties or characteristics of CAS (see for example Levin, 1998; Eoyang & Berkas, 1999; Holland, 2006; Schneider & Somers, 2006; Stockholm Resilience Centre, 2014).

SES are CAS in which the social and ecological domains are inextricably linked (Walker et al., 2002; Anderies et al., 2004; Folke et al., 2005). The interconnectedness of the two domains makes the delineation between the social and ecological systems arbitrary and necessitates their consideration as one co-evolving system (Berkes & Folke, 2002; Folke et al., 2005; Adger, 2006; Levin et al., 2013). As such, Folke et al. (2005) note that analyses of SES necessarily differ from those of social systems or ecological systems alone. For example, the element of human agency and intentionality in SES introduces an additional layer of complexity to the consideration of system dynamics (Shearer, 2005; Walker et al., 2006). As Levin et al. (2013, p. 113) point out, individual agents in SES are able to "change, to learn from experience (or to change in relative abundance over evolutionary time) and to exploit their own selfish agendas. These agents compete for limited resources, leading to behaviors of exploitation, competition, parasitism and cooperation". Considering systems of people and nature as linked SES facilitates thinking about the ways in which the social and ecological domains influence, and are influenced by, one another and emphasizes the importance of these connections (Grimm et al., 2000; Alberti et al., 2003; Folke et al., 2003).

Understanding systems as CAS and more specifically, linked SES, is fundamental to resilience thinking (Folke, 2006; Walker & Salt, 2006). This study uses the specific lens of social-ecological resilience. Social-ecological resilience is a concept that describes the ability of a system to cope with, adapt to, and shape change without compromising future adaptability (Folke et al., 2003). Social-ecological resilience is an appropriate lens for this research, given that aquatic ecosystems are SES, and efforts to restore these systems must take into consideration their dynamic nature (Ebersole et al., 1997; Hilderbrand et al., 2005; Palmer et al., 2005). Rather than attempting to maintain an aquatic ecosystem in a particular state, ecological restoration informed by social-ecological resilience should be concerned with maintaining, enhancing, or degrading the resilience of the system based on its current trajectory. This alternative approach is based on engaging with, as opposed to fighting, change and accepting complexity, uncertainty, and unpredictability, as well as the existence of thresholds and the potential for regime shifts (Kay et al., 1999; Folke et al., 2002; Anderies et al., 2006; Walker & Salt, 2012).

The remainder of this section provides a broad overview of social-ecological resilience. First, a brief summary is provided of how resilience thinking, defined as a concept that "addresses the dynamics and development of complex social-ecological systems" (Folke et al., 2010, online), has evolved over several decades from its roots in ecology. A review of three key articles that mark the current state of knowledge on resilience thinking with regard to complex SES follows. Finally, the challenge of applying resilience concepts on the ground, in real-life situations, is discussed along with examples of how this has been approached in several situations.

2.3.2 Social-Ecological Resilience

Before the concept of resilience gained recognition in the field of ecology, the ecological stability viewpoint was the dominant means of characterising systems (Holling, 1973). The stability viewpoint suggests that ecological systems operate at, or near, a single equilibrium and if disturbed, a system will return to equilibrium (Holling & Meffe, 1996; Gunderson, 2000; Folke et al., 2004; Gunderson & Allen, 2010). The faster the return to equilibrium and the greater the disturbance a system is capable of recovering from, the more stable and hence, the more desirable the system is considered to be (Holling & Meffe, 1996; Berkes & Folke, 1998; Holling et al., 2002; Folke et al., 2004). The belief that relationships between system elements are linear and, therefore, predictable, reinforces the notion that humans can manipulate ecological systems to heighten productivity and consequently, increase human benefit (Holling, 1987; Kay et al., 1999; Holling et al., 2002). An approach to natural resource management involving the manipulation and control of ecological systems for human benefit is termed command and control (Holling & Meffe, 1996; Waltner-Toews et al., 1999; Gunderson, 2000; Folke et al., 2003; Berkes, 2004). As a result of the command and control approach, numerous examples of system degradation and collapse have been observed (Holling & Meffe, 1996; Folke et al., 2004), throwing into question the ecological stability perspective. As early as the 1970s, Holling (1973, p. 2) asserted that the stability viewpoint, which he termed engineering resilience, does not adequately describe "the transient behavior of systems that are not near the equilibrium". This realisation exposed the need for a shift in the characterisation of ecological systems.

Holling's (1973) work on ecological resilience was a response to the inadequacies of the ecological stability view. From his work with model ecosystems and observations of real systems, Holling (1973) identified that ecological systems have stability landscapes exhibiting more than one stability domain, each with its own attractor. A system can exist in one stability domain and subsequently cross a threshold into a different stability domain as a result of natural and/or anthropogenic disturbances (Holling & Meffe, 1996; Kay et al., 1999; Gunderson, 2000; Kay, 2000; Folke et al., 2004; Kinzig et al., 2006). It can be argued that ecological resilience overlaps to an extent with catastrophe theory (Thom, 1975) which also gained popularity in the 1970s. Catastrophe theory, according to Lockwood & Lockwood (2008, online), is a "framework for the study of discontinuous phenomena in normally continuous systems". Catastrophe theory has been used to characterize the existence of multiple basins of attraction with regard to dynamic systems (Levin & Lubchenco, 2008) and has been applied to describe sudden responses of populations to slow environmental changes (Lockwood & Lockwood, 2008). Ecological resilience is defined as the "capacity of a system to absorb disturbance and reorganize while undergoing change so as to retain essentially the same function, structure, identity, and feedbacks" (Folke et al., 2004, p. 558). Ecological resilience can be desirable, as in the case of a clear water lake, or undesirable, as in the case of a eutrophic lake (Carpenter et al., 2001; Cumming et al., 2005; Brand & Jax, 2007). Furthermore, whether the resilient configuration a system is within is considered desirable or undesirable is a matter of perspective (Lebel et al., 2006).

While ecological resilience describes a great deal of the complexity observed in systems, the connection between social and ecological systems is not explicitly addressed (Holling et al., 2002; Folke, 2006). Social systems are reliant on ecological systems for numerous critical ecosystem services (Carpenter et al., 2006), but they also exert a great deal of influence on ecological systems (Rockström & Karlberg, 2010; Steffen et al., 2011). Steffen et al. (2011) discuss this relationship in their work on the Anthropocene. The authors argue that the Earth system is now entering the period known as the Anthropocene, in which humans have become the primary geological force changing the planet (Steffen et al., 2011).

Social-ecological resilience builds on the concept of ecological resilience by acknowledging the interconnected relationship between social and ecological systems

(Folke et al., 2003; Plummer, 2010). SES are characterized by complexity, uncertainty, unpredictability, thresholds, tipping points, regime shifts, and cascading effects (Waltner-Toews et al., 1999; Berkes & Jolly, 2001; Holling et al., 2002; Walker et al., 2002; Anderies et al., 2006; Kinzig et al., 2006; Walker et al., 2006). The dynamics of such systems involve the interplay of stabilizing and destabilizing forces (Holling, 1996). Accordingly, social-ecological resilience is defined as "(1) the amount of disturbance a system can absorb and still remain within the same state or domain of attraction, (2) the degree to which the system is capable of self-organization (versus lack of organization, or organization forced by external factors), and (3) the degree to which the system can build and increase the capacity for learning and adaptation" (Folke, 2006, pp. 259-260). As Folke's (2006) definition suggests, the resilience of a SES refers to more than the capacity to absorb perturbations. A resilient SES in a desirable configuration also has the capacity for renewal and innovation (Berkes et al., 2003), is able to take advantage of opportunities created by disturbance (Folke, 2006; Plummer, 2010), and builds knowledge and understanding of resource and ecosystem dynamics (Berkes & Folke, 1998; Olsson et al., 2004; Walker et al., 2004; Folke, 2006).

2.3.3 Resilience Thinking

In the time since Holling's (1973) seminal work on ecological resilience, the number of scholarly articles and books on the topic of resilience has grown significantly and appears to be continuing along this trend (Janssen, 2007; Xu & Marinova, 2013). In addition, several internationally recognized research organizations and centres are primarily focused on the advancement of the state of knowledge on resilience and its associated concepts (Stockholm Resilience Centre, 2015; The Beijer Institute of Ecological Economics, 2015; Resilience Alliance, 2015). Furthermore, resilience has moved beyond the scholarly community and has become an important concept in intergovernmental initiatives (OECD, 2013), international campaigns (UNISDR, 2012), national programs (UK Government, 2014), and regional planning efforts (Namoi Catchment Management Authority Board, 2013). Evidently, there is a plethora of information available related to resilience thinking and the concept has been used in a wide variety of contexts (Bhamra et al., 2011; Biggs et al., 2012).

Several key articles have attempted to summarize the state of knowledge on resilience thinking, specifically with regard to complex SES. For instance, Folke et al. (2003) identify four critical factors for building resilience for adaptive capacity highlighted throughout case studies presented in the chapters of their book titled *Navigating social-ecological systems: building resilience for complexity and change*. The critical factors – learning to live with change and uncertainty, nurturing diversity for reorganization and renewal, combining different types of knowledge for learning, and creating opportunity for self-organization – are behavioural responses to environmental issues and change that interact across temporal and spatial scales and appear to be required for managing resource dynamics in SES (Folke et al., 2003). Another example is the work of Plummer et al. (2014b) which focuses on aquatic ecosystems and the key attributes for governing these systems to ensure resilience. Using the Delphi method, Plummer et al. (2014b) developed scholarly consensus around eight governance attributes that indicate specified resilience, as well as five attributes that signify general resilience. The attributes identified as a result of the Delphi study mark the current state of knowledge among experienced scholars regarding governance for resilience of aquatic systems.

A third example is Biggs et al.'s (2012) seven principles for building resilience of ecosystem services. The principles are purportedly applicable to SES broadly and as such, they are well-suited to contribute to the purpose of this research. These seven generic principles considered crucial for building resilience in SES were developed based on an assessment of the resilience literature, a modified Delphi survey of leading resilience experts, and a mock court workshop (Biggs et al., 2012). The principles have since become the focus of a publication produced by the Stockholm Resilience Centre (Simonsen et al., 2014) and a book published in 2015 which expands on the initial review article by offering insights on how the principles can be practically applied and examples of how and where this has been done (Biggs et al., 2015). A brief description of each of the seven principles is provided in Table 2.2. The first three principles listed in Table 2.2 focus on generic SES properties and processes to be managed while the remaining four principles relate to key properties of SES governance (Biggs et al., 2012). Despite these groupings, the authors stress that the seven principles are often highly interdependent (Biggs et al., 2012).

2.3.4 Resilience Practice

Resilience thinking has received a great deal of attention (Xu & Marinova, 2013) and has been endorsed as a helpful approach to "structuring the study and management of social-ecological systems" (Anderies et al., 2006, online). For these reasons, Walker and Salt (2012) suggest that the natural next step is to put resilience thinking and its associated concepts into practice. Interest in transitioning from resilience thinking to resilience practice, in real world situations, has been growing in recent years (Biggs et al., 2012; Walker & Salt, 2012; Wilkinson, 2012; Mitchell et al., 2014; Plummer et al., 2014b). However, resilience concepts are notoriously difficult to translate into action on the ground and document in practice (Miller et al., 2010).

The need to move from resilience thinking to resilience practice, and the challenges associated with this task, have been referred to many times in the scholarly literature on the subject (Peterson, 2002; Cumming et al., 2005; Miller et al., 2010; Walker & Salt, 2012; Plummer et al., 2014b). Miller et al. (2010) argue that one of several reasons why this transition is so difficult is because of a limited amount of detailed guidance on how to actually undertake actions to build resilience. At the same time, the authors acknowledge the danger in detailed manuals or 'cookbooks' for governing complex SES (Miller et al., 2010). Evidently, a balance must be struck between providing guidelines that are specific enough to assist practitioners in answering questions, such as which actors to involve and what sort of management options exist, and offering guidance that is flexible enough to appreciate the great deal of variation within and across SES (Miller et al., 2010).

Table 2.2 Principles for building resilience in SES (adapted from Biggs et al., 2012)

1. *Maintain diversity and redundancy*
   When confronted with disturbance, the existence of functional redundancy means that, while some components of the system may be lost, those that remain compensate for the loss. When components within the same functional group exhibit diversity in their response to a certain disturbance, redundancy is considered even more valuable. Diversity and redundancy provide options for responding to change and confronting uncertainty, thereby building resilience.
2. *Manage connectivity*
   Connectivity in SES refers to both the nature and strength of interactions between system components. Connectivity can positively or negatively influence a system. High connectivity is considered to be important in aiding recovery following a disturbance but disturbance also spreads faster in highly connected systems. Therefore, the key is managing an appropriate level of connectivity given the specific context of the system.
3. *Manage slow variables and feedbacks*
   Managing slowly changing variables and positive and negative feedbacks that influence the configuration of a system is critical to avoid crossing a threshold. Feedbacks that maintain desirable system configurations should be strengthened and the key slow variables should be monitored for their proximity to thresholds. Additionally, governance structures capable of effectively responding to monitoring data must be established.
4. *Foster CAS thinking*
   Although fostering CAS thinking may not directly enhance the resilience of a system, it does contribute to building it. Considering SES as CAS requires disengaging from steady-state reductionist thinking and accepting unpredictability, uncertainty, and variability. Changing how complex systems are understood is the first step in altering behaviour in favour of practices that build resilience.
5. *Encourage learning and experimentation*
   Uncertainty and the dynamic nature of complex SES require that learning remain an ongoing part of managing a system to enhance resilience. Potential mechanisms for encouraging learning and experimentation include adaptive management, adaptive co-management, and adaptive governance. Also highlighted in these approaches is the importance of knowledge sharing among actors and across scales.
6. *Broaden participation*
   Engaging relevant stakeholders in the management of SES builds resilience by bringing together diverse types and sources of knowledge. Stakeholder engagement enhances capacity for collective action through building a shared understanding and improving trust and legitimacy. However, participation of all relevant stakeholders in all stages of management is not always feasible or desirable. Broad participation is particularly useful when management needs and priorities are being debated and determined.
7. *Promote polycentric governance systems*
   Polycentric governance helps ensure that problems are addressed at the appropriate scale, by the right individuals. Polycentric governance enhances resilience by improving connectivity, creating modularity, enabling broader levels of participation and providing opportunities for learning and experimentation, improving potential for response diversity, and by building redundancy that can minimize and correct governance errors.

Six years after publishing their book on resilience thinking, Walker and Salt (2012) published a sequel that appears to address the aforementioned lack of guidance on undertaking actions to build resilience in the real world. In this book, the authors define resilience practice as “the capacity to work with the system in order to apply resilience thinking, to manage its resilience” (Walker & Salt, 2012, p. 18). The authors offer a general approach to putting resilience into practice consisting of three guiding steps –

describe the system, assess its resilience, and manage that resilience (Walker & Salt, 2012). The chapters of the book go through each of these guiding steps and offer a variety of ways to undertake them. In this way, Walker and Salt's (2012) book does not provide a recipe or strict guidelines for resilience practice but rather offers options and guidance. In their concluding chapter, the authors describe several emergent themes for effective resilience practice. These emergent themes include thinking in terms of multiple scales, putting a focus on thresholds, celebrating change, embracing uncertainty, fostering innovation, and pursuing adaptive governance (Walker & Salt, 2012).

Additional efforts to provide guidance to practitioners looking to operationalize resilience concepts, and examples of practitioners actually going forward and experimenting with these ideas are appearing despite the many associated challenges (Miller et al., 2010; Walker & Salt, 2012; Krievins et al., 2015). For instance, the Resilience Alliance offers a free workbook online to assist scientists and practitioners in undertaking resilience assessments (Resilience Alliance, 2007; 2010). Several recent articles cite the use of these workbooks for carrying out resilience assessments in very different contexts (see Haider et al., 2012; Wilkinson, 2012; Sellberg et al., 2015). Other examples of moving from resilience thinking to resilience practice include the use of Tyler and Moench's (2012) operational framework for planning practitioners in 10 cities across Asia. Tyler and Moench (2012, p. 311) explain that the framework "integrates theoretical and empirical knowledge of the factors contributing to resilience with processes for translating those concepts into practice". The application of resilience thinking has also been explored in the rural community of Wakool Shire in Australia, particularly with regard to undergoing transformative change prompted by a period of severe and prolonged drought (Mitchell et al., 2014). Also in Australia, but on a larger scale, the eleven Catchment Management Authorities of the state of New South Wales are utilizing resilience as a basis for their regional catchment action plans (see for example Namoi Catchment Management Authority Board, 2013). Furthermore, Walker and Salt (2012) contend that workshops on various aspects of resilience practice have been held all around the world.

In Canada, resilience analysis workshops specific to aquatic ecosystems have been held in the Hammond River Watershed in New Brunswick and the Cowichan Watershed in British Columbia (Baird et al., 2016). These resilience analysis workshops provided an opportunity for watershed stewards to come together and explore how resilience thinking can build on and complement existing plans (Plummer et al., 2014a). Over the duration of the workshops, participants worked through exercises to describe their system, with consideration of the scales above and below, in terms of values, disturbances, drivers of change, specified and general resilience, and adaptive capacity (Plummer et al., 2014a). The workshops were intended as a starting point for these groups to consider applying resilience concepts in their watersheds. Baird et al. (2016) note some promising signs in the Cowichan Watershed of resilience concepts beginning to be taken up following the resilience analysis workshop.

With respect to ecological restoration, there are few documented examples of attempts to apply social-ecological resilience concepts despite their increasingly frequent appearance in the restoration ecology literature. Parks Canada's (2008) guide to ecological restoration in Canada's protected natural areas is an exception as its planning and implementation process is based on guidelines for restoration that are influenced by resilience thinking. Another example is Harris et al.'s (2012) technical manual for watershed groups which applies resilience thinking to the planning and implementation of restoration projects on Prince Edward Island. Moreover, the program from the 2015 SER world conference titled *Towards resilient ecosystems: restoring the urban, the rural and the wild* provides reason to believe that examples of resilience practice in ecological restoration will become more numerous in the future (SER, 2015).

In summary, a review of the literature on moving from resilience thinking to resilience practice suggests that on the one hand, this is a very difficult task for a number of valid reasons (Miller et al., 2010). On the other hand, applying resilience concepts in practice is too important to accept inaction (Folke et al., 2010; Biggs et al., 2012; Walker & Salt, 2012), as is evidenced by the growing number of experiments with resilience practice (Haider et al., 2012; Tyler & Moench, 2012; Wilkinson, 2012; Sellberg et al., 2015; Baird et al., 2016).

2.4 Synthesis and Conceptual Intersections

The preceding sections of this literature review raise the possibilities to relate ecological restoration and social-ecological resilience. Objective One of this thesis is to explore how insights from social-ecological resilience may inform ecological restoration and in bringing these two areas together, develop a conceptual framework that will guide this investigation. To that end, this final section provides a synthesis of the major issues from sections 2.2 and 2.3 and explores their conceptual intersection points.

Two major issues were highlighted in section 2.2 on ecological restoration. First, based on the review of the ecological restoration literature, it was suggested that new approaches to ecological restoration are needed that more accurately reflect the complexity of the systems being restored. Not only is it important to understand these systems as CAS, but also to recognize social considerations such as laws, policies, institutions, and the values and interests of individuals. Many restoration project failures are at least partially attributable to an oversimplified understanding of the system of concern which can include the failure to acknowledge the interconnections between the social and biophysical domains and/or the tendency to overlook change as an inherent and important part of dynamic systems. Second, the dearth of evaluation in ecological restoration was exposed as a significant concern. Without evaluation, little can be said about which restoration techniques or approaches are effective. Hence, evaluating the outcomes of restoration initiatives was highlighted as being critical to advancing the science and practice of ecological restoration.

Section 2.3 brought forth several key points with regard to social-ecological resilience. Social-ecological resilience was presented as a framework for thinking about CAS as SES exhibiting uncertainty, unpredictability, thresholds and tipping points, and experiencing regime shifts and cascading effects. Moreover, a resilient SES was described, not only in terms of the capacity to absorb perturbations, but also the capacity for renewal, innovation, and building knowledge and understanding of resource and ecosystem dynamics. The works of Folke et al. (2003), Plummer et al. (2014b), and Biggs et al. (2012), were provided as examples of efforts summarizing the state of knowledge on resilience thinking. Each example highlighted offers a set of factors, attributes, or principles for maintaining or enhancing the resilience of SES. The section concluded with a discussion around recent attempts to translate resilience thinking concepts, not unlike those presented in the aforementioned articles, into practice with limited examples specific to ecological restoration.

The conceptual intersections between these two areas of scholarship, particularly the major issues raised in section 2.2 and the key points highlighted in section 2.3, are brought together in Figure 2.1. Consideration of the general phases of ecological restoration process outlined in section 2.2.4 provides a starting point. Shown in Figure 2.1, these five phases, or common steps, were derived from several sets of guidelines established for ecological restoration initiatives broadly, as well as procedures described for stream restoration initiatives more specifically. The phases – problem identification, defining goals and objectives, designing a restoration plan, implementation, and monitoring and evaluation – are intended to capture the general process undertaken in a broad range of restoration initiatives in order to provide a common, straightforward means of thinking about, and communicating different approaches to, restoration initiatives.

In section 2.3.3, Biggs et al.'s (2012) seven generic principles considered crucial for building resilience in SES were introduced and described in Table 2.2. These principles, including three principles focusing on generic SES properties and processes to be managed, and four principles related to key properties of SES governance, are selected to guide this study because they represent the current state of knowledge on the principles required for building resilience and are considered to be applicable to any SES. For these reasons, the principles shown in Figure 2.1 are well suited to the consideration of the social-ecological resilience of aquatic ecosystems and thus, are well-positioned to contribute to this study.

Figure 2.1 illustrates how the general phases of ecological restoration process and generic principles for building resilience in SES may conceptually come together in the specific context of aquatic ecosystem restoration. Each of Biggs et al.'s (2012) seven principles can inform the five general phases of the ecological restoration process. Although each principle is understood to be relevant to all five phases of the restoration process, there are undoubtedly phases where certain principles will play a more, or less, important role than others. Context is a critical consideration in determining what those differences look like. As one example, some restoration initiatives undertaken on private land are restricted in terms of the amount of participation allowed in the implementation phase. On the other hand, a large riparian planting initiative in a public park presents an excellent opportunity for broad participation from a wide range of groups including the general public, school groups, businesses, government agencies, and others. The large variation in the size and complexity of restoration initiatives suggests that the ways in which the principles are expressed in each phase will inevitably look different and as a result, the social and ecological outcomes will vary accordingly. With these considerations in mind, Figure 2.1 is not prescriptive in nature, rather it communicates the potential for the seven generic principles for building resilience in SES to influence or inform the five general phases of ecological restoration process.

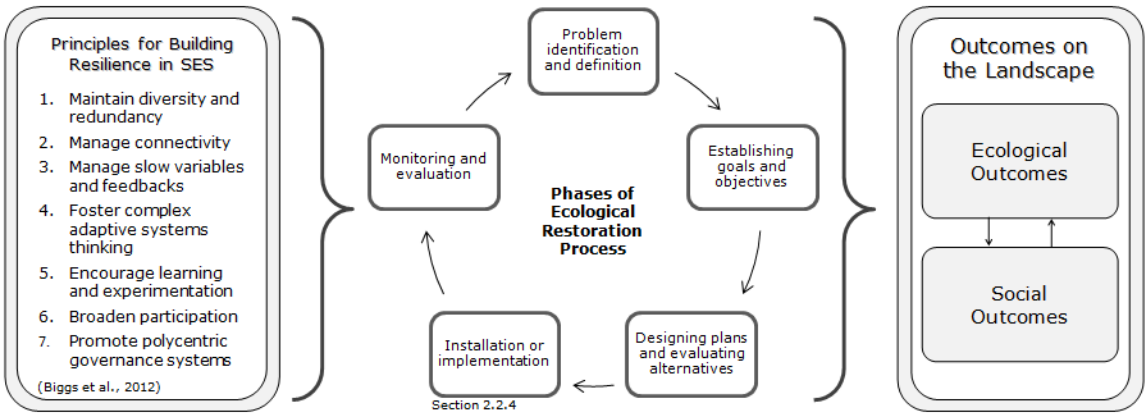

Figure 2.1 Conceptual framework illustrating the potential for Biggs et al.'s (2012) principles for building resilience in SES to inform the phases of the ecological restoration process, ultimately resulting in ecological and social outcomes on the landscape. Monitoring and evaluation of restoration outcomes subsequently informs the next iteration of the restoration process starting back at problem identification and definition.

Figure 2.1 also shows that a restoration process informed by the principles for building resilience consequently manifests on the landscape as a series of social and ecological outcomes. This relationship between restoration process and outcomes is significant and should not be overlooked. While a restoration process informed by principles for building resilience in SES is conceptually sound, empirically evaluating the subsequent expression on the landscape in terms of social and ecological outcomes is critical to understanding if this new approach to restoration ultimately results in positive outcomes. Social and ecological outcomes of such restoration initiatives are considered in this study in relation to Objective Three.

Chapter Three: Methodology

3.1 Introduction

The potential for social-ecological resilience to inform aquatic ecosystem restoration was conceptually explored in Chapter Two. This chapter describes the methodology employed in undertaking the empirical portion of the research to achieve Objectives Two and Three. The remainder of the chapter is divided into four sections. The first section focuses on the case study methodology, why it was chosen for this research and the selection of the case and embedded subunits. The second section explains how the conceptual framework guiding this research was developed and subsequently operationalized for the assessment of the training program and evaluation of restoration initiatives. The third section outlines the data collection protocol followed by the final section describing the treatment of those data.

3.2 Case Study Methodology

3.2.1 Rationale for Choosing the Case Study Method

The decision to use a single-case, embedded case study design for this research was informed by the research purpose and objectives. Case studies are practical in situations where a researcher wishes to examine contemporary events or gain an in-depth understanding of a real-world case within its context (Scholz & Tietje, 2002; Gagnon, 2010), but behaviours cannot be manipulated as in an experiment (Yin, 2014). The use of the case study method allowed for this research to move from exploring the conceptual intersections between ecological restoration and social-ecological resilience to empirically investigating those intersections using a real stream restoration training program. Additionally, multiple methods can be used within a case study yielding a variety of evidence (Gillham, 2000). Given the nature of this research, bridging social and ecological dimensions, the case study approach was appropriate as it “relies on multiple sources of evidence, with data needing to converge in a triangulating fashion” (Yin, 2009, p. 18).

Single-case, case study research designs can be holistic with one unit of analysis and no subunits, or embedded with attention given to two or more subunits within a single case (Scholz & Tietje, 2002; Yin, 2014). Yin (2014) contends that examining embedded subunits can add opportunities for analysis and enhance insights into a case. Embedded subunits were included in this research to create an opportunity to understand how the lessons from the training program are being incorporated into restoration process and whether practical applications of the concepts taught in the program have led to desired social and ecological outcomes. Using multiple subunits for this purpose was ideal given the diversity of restoration initiatives that could possibly be evaluated. Aquatic ecosystem restoration initiatives can vary greatly in terms of scale, ranging from focusing on a specific reach to addressing issues across an entire watershed. Initiatives can also vary significantly with regard to timescale with some projects being one-off projects and others, multi-year programs. Furthermore, the techniques utilized in aquatic ecosystem restoration span from basic but effective techniques requiring nothing more than hand tools and human power, to extensively planned and meticulously executed techniques involving heavy machinery and specialized equipment.

3.2.2 Case Selection

The Stream Rehabilitation, From Form to Function Training Program was selected as the unit of analysis for this case study research. The program was developed over several years in response to renewed interest in stream stewardship in Ontario (Imhof & FitzGibbon, 2014) and in recognition of the fact that the majority of volunteer groups were lacking the necessary knowledge and training to develop and implement restoration projects. Furthermore, many of the individuals involved in pioneering stream rehabilitation in Ontario in the preceding decades were retiring or otherwise not involved in the field anymore (J. Imhof, personal communication, May 5, 2015). As such, the need to train the next generation of experts to carry on the work that had been started became evident and spurred conversation among a number of conservation organizations and individuals on how to address this issue (Imhof & FitzGibbon, 2014). The stewardship councils in Brant, Waterloo, and Wellington started the process by holding a series of workshops with the intent of training, supporting, and providing resources to groups and individuals wishing to engage in aquatic renewal of their local streams (Imhof, 2010). The initial workshops were followed by the development of a formal training program, the result of a collaborative effort involving a consortium of conservation organizations and individuals led by TUC (Imhof, 2010). The workshops are presently offered by TUC with the aim of training volunteers and young professionals to become the new leaders in aquatic renewal.

Although other stream restoration training programs and courses exist and were identified through an internet search, TUC's training program was unique in that it appeared to be based on a CAS thinking approach to stream restoration. For example, based on descriptions of the training program and its workshops found online, the program seemed to emphasize gaining an understanding of the watershed as a whole including multiple spatial scales and both social and ecological domains. Furthermore, the workshops collectively cover the general phases of the restoration process and purport to be based on the most current science (TUC, 2016), acknowledging that our understanding of watersheds and restoration continue to evolve. Conversely, other training programs and courses identified appeared to focus on select aspects of restoration such as design or monitoring and/or largely avoid addressing social aspects of restoration (see for example NOAA Habitat Conservation, n.d.; UNB, 2013; NCSU SRP, 2016; Wildland Hydrology, 2016). For these reasons, the TUC training program was chosen as an ideal unit of analysis for this exploratory case study (Baxter & Jack, 2008). Unlike explanatory case studies which seek to establish cause-and-effect relationships (Hancock & Algozzine, 2011) and descriptive designs intended to present a complete description of a phenomenon and the real-life context in which it occurred (Baxter & Jack, 2008), an exploratory case study is particularly useful in situations where the intervention being evaluated does not have a single set of clear outcomes (Yin, 2003). Objective Two of this study is to assess a training program in relation to social-ecological resilience to ascertain the degree to which it aligns with the principles presented in the conceptual framework and in doing so, reveal the extent to which the training program represents a case of a novel approach to ecological restoration.

Restoration initiatives informed by the training program served as the embedded subunits examined within this case. To be considered an embedded subunit, a past trainee of the program who had completed all six of the training program workshops had to have led or been extensively involved in the initiative and have self-identified the initiative as being informed by the training program. A key informant from TUC provided the names and contact information of several past trainees from TUC's database who satisfied the aforementioned criteria and who gave permission for their information to be shared for research purposes.

3.3 Developing and Operationalizing the Conceptual Framework

The first objective of this study is to conceptually explore how social-ecological resilience may inform aquatic ecosystem restoration and its evaluation. A review of the literature on social-ecological resilience and ecological restoration revealed intersection points between these two areas of scholarship. More specifically, the potential for Biggs et al.'s (2012) seven principles for building resilience in SES to influence or guide each of the five general phases of ecological restoration process outlined in section 2.2.4 was described. This relationship and its ultimate expression on the landscape in terms of social and ecological outcomes is captured and illustrated in the conceptual framework presented in Figure 2.1 in section 2.4. Transitioning from conceptually exploring the intersections between two areas of scholarship to empirically investigating the training program and restoration initiatives required operationalizing the conceptual framework.

In line with Objective Two, to assess a training program for aquatic ecosystem restoration in relation to social-ecological resilience, the conceptual framework was made operational through the development of an assessment framework (Table 3.1). The assessment framework guided both data collection and analysis. As shown in Table 3.1, the principles for building resilience in SES are listed down the left hand column and the phases of ecological restoration process are shown across the top row. This layout demonstrates that each of the five phases from problem identification through to monitoring and evaluation may be informed by Biggs et al.'s (2012) seven principles. Accordingly, assessing the training program in relation to social-ecological resilience could potentially reveal evidence of the principles in what is taught about each phase of the restoration process. In order to determine what would constitute expressions of the principles, a set of criteria was established (Table 3.2). As a result of the highly interconnected and interdependent nature of the principles (Biggs et al., 2012), it is important to acknowledge that boundaries between criteria are best described as 'fuzzy'. This relationship between principles is discussed further with regard to the treatment of data (section 3.5).

To satisfy Objective Three, to evaluate aquatic ecosystem restoration initiatives informed by the training program in terms of social-ecological resilience, an evaluation framework (Table 3.3) was created based on the conceptual framework. The evaluation framework guided data collection and analysis pertaining to the evaluation of restoration initiative process and outcomes. The evaluation framework is similar to the assessment framework with the exception of an additional set of columns on the right side specific to restoration outcomes. Ecological outcomes were considered in relation to the three principles categorized as key SES properties to be managed. Conversely, social outcomes were considered in terms of the final four principles categorized as key attributes of the governance system. Although social outcomes pertain to all of the principles, ecological restoration is the primary focus of this study and evaluating all social outcomes, while important, was beyond the scope of the study. An evaluation of the social outcomes in relation to the principles considered key SES properties to be managed would involve a more in-depth social analysis than would be possible in this study given limitations of time and resources. The use of the letters 'NA' for 'not assessed' in Table 3.3 reflects this distinction between social outcomes that were possible to assess in this study and those that were not. The set of criteria defined in Table 3.2 was also used for the evaluation of restoration initiatives.

Table 3.1 Framework for assessing the Stream Rehabilitation, From Form to Function Training Program in relation to social-ecological resilience

<table>
<tr><td colspan="3" rowspan="2"></td><th colspan="5">GENERAL PHASES OF ECOLOGICAL RESTORATION PROCESS</th></tr>
<tr><th>Problem identification</th><th>Defining goals and objectives</th><th>Designing a restoration plan</th><th>Implementation</th><th>Monitoring and evaluation</th></tr>
<tr><th rowspan="7">PRINCIPLES FOR BUILDING RESILIENCE IN SES</th><th rowspan="3">Key SES properties to be managed</th><td>Maintain diversity and redundancy</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Manage connectivity</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Manage slow variables and feedbacks</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><th rowspan="4">Key attributes of the governance system</th><td>Foster CAS thinking</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Encourage learning and experimentation</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Broaden participation</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Promote polycentric governance systems</td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Table 3.2 Criteria for judging the presence of principles for building resilience (Biggs et al., 2012) in the general phases of ecological restoration process

Principle	Criteria	Examples
Maintain diversity and redundancy	*Diversity of system components* • Refers to the variety of elements in a system such as species and landscape patches, as well as the balance, or the proportion of each element, and how different those elements are from one another. *Functional redundancy* • Property of a system describing the presence of multiple components capable of contributing in equivalent ways to a particular function. *Response diversity* • The range of reactions or responses that components contributing to the same function have to change and disturbance.	• A variety of native species that complement the surrounding landscape are included in riparian planting plans • Live stakes, live fascines, and seeding are all used for the purpose of bank stabilization and erosion control • Project funding is reliant on more than one source
Manage connectivity	*Appropriate structure of interactions between system components* • Pertains to links between system components both in terms of presence or absence of links as well as the distribution of links within a system. *Appropriate strength of interactions between system components* • Refers to the intensity of the connections between system components.	• Landowners are educated about the importance of maintaining a riparian buffer to reduce fragmentation of the riparian corridor • Regular contact with relevant stakeholders is maintained throughout the duration of the restoration project to provide updates and receive feedback
Manage slow variables and feedbacks	*Feedbacks are managed appropriately* • Feedbacks that maintain desirable system configurations are strengthened and those that perpetuate undesirable configurations are disrupted. *Key slow variables are monitored* • Slow variables such as soil composition, legal systems, and values that determine the underlying structure of SES are monitored in terms of their proximity to thresholds.	• Bioengineering is used over hard-engineering and where possible, hard-engineered structures are replaced with more natural solutions • Changing attitudes are capitalized on by working with landowners to fence cattle out of creeks and/or restore a natural buffer
Foster CAS thinking	*Holistic approaches are emphasized* • Refers to approaches that look at the system as a whole including interactions with scales above and below the focal scale. *Unpredictability, uncertainty, and variability are accepted* • Plans and decisions are made with the acknowledgement that change and surprise are inevitable and that solutions are context dependent. Restoration is adaptive to changing conditions.	• Problem identification involves looking beyond the reach scale to address causes, rather than symptoms, of problems • Goals and objectives focus on restoring ecosystem processes and functions rather than a specific historic or static state
Encourage learning and experimentation	*Willingness to experiment* • Openness to actively manipulating certain SES processes and structures in novel ways to observe and evaluate outcomes. *Knowledge sharing among actors and across scales* • Knowledge shared at and beyond the focal scale.	• Different species are experimented with for stabilizing banks to see what is most effective in a particular situation • Restoration outcomes are shared through social media and traditional mediums to reach a wide

	Collaborative and long-term monitoring • Long-term collection of information about changes in SES carried out by several parties, not just specialist agencies.	audience across scales • As part of a monitoring effort, anglers are encouraged to record and share information about fish species caught, as well as, any notable changes in the condition of the aquatic ecosystem
Broaden participation	*Relevant stakeholders are actively engaged* • Engagement of those who are actively interested in, directly impacted by, or are able to provide applicable local or scientific knowledge to a restoration initiative. Depending on the context, engagement can vary greatly from informing stakeholders of plans and activities to inclusion in all stages of the restoration process.	• Community members are invited to attend public meetings or open houses and are encouraged to ask questions about, and provide comment on, restoration plans and alternatives
	Diverse types and sources of knowledge are brought together • Different types and sources of knowledge are welcomed and considered including local or experiential knowledge.	• Partnerships are formed between research institutions, conservation organizations, industry, and others to explore potential solutions to identified problems
Promote polycentric governance systems	*Multiple governing authorities at different scales* • Deliberation and decision-making among multiple groups at different scales with various sources of authority, thereby allowing decision making to match the scale of the problem.	• A non-governmental organization, a Conservation Authority representative, and a landowner discuss and make decisions on the details of a small-scale restoration project on private property
	Governance units have horizontal linkages • Refers to governance units' links with others at the same scale on common issues.	• Information and experiences are shared with community organizations in neighbouring watersheds
	Governance units have vertical linkages • Refers to governance units' nesting within, and linkages with, scales above and below the focal scale.	• The organization leading a restoration initiative seeks advice from provincial and/or federal agencies as required

Table 3.3 Framework for evaluating process and outcomes of restoration initiatives in relation to social-ecological resilience

<table>
<tr><th colspan="3" rowspan="2"></th><th colspan="5">GENERAL PHASES OF ECOLOGICAL RESTORATION PROCESS</th><th colspan="2">RESTORATION OUTCOMES</th></tr>
<tr><th>Problem identification</th><th>Defining goals and objectives</th><th>Designing a restoration plan</th><th>Implementation</th><th>Monitoring and evaluation</th><th>Ecological outcomes</th><th>Social outcomes</th></tr>
<tr><td rowspan="7">PRINCIPLES FOR BUILDING RESILIENCE IN SES</td><td rowspan="3">Key SES properties to be managed</td><td>Maintain diversity and redundancy</td><td></td><td></td><td></td><td></td><td></td><td></td><td>NA</td></tr>
<tr><td>Manage connectivity</td><td></td><td></td><td></td><td></td><td></td><td></td><td>NA</td></tr>
<tr><td>Manage slow variables and feedbacks</td><td></td><td></td><td></td><td></td><td></td><td></td><td>NA</td></tr>
<tr><td rowspan="4">Key attributes of the governance system</td><td>Foster CAS thinking</td><td></td><td></td><td></td><td></td><td></td><td>NA</td><td></td></tr>
<tr><td>Encourage learning and experimentation</td><td></td><td></td><td></td><td></td><td></td><td>NA</td><td></td></tr>
<tr><td>Broaden participation</td><td></td><td></td><td></td><td></td><td></td><td>NA</td><td></td></tr>
<tr><td>Promote polycentric governance systems</td><td></td><td></td><td></td><td></td><td></td><td>NA</td><td></td></tr>
</table>

NA = not assessed

3.4 Data Collection

A mixed methods approach was used in this research, bringing together qualitative and quantitative methods of data collection. Johnson and Onwuegbuzie (2004, p. 17) define mixed methods research as a class of research in which "the researcher mixes or combines quantitative and qualitative research techniques, methods, approaches, concepts or language into a single study". Although purists argue the superiority of either qualitative or quantitative research (see for example Schrag, 1992; Lincoln & Guba, 2000), many social scientists recognize the importance and usefulness of both paradigms and point out the advantages of bringing the two together (Tashakkori & Teddlie 1998; Johnson & Onwuegbuzie, 2004; Creswell, 2009). By utilizing the strengths and minimizing the weaknesses of both quantitative and qualitative methods (Johnson & Onwuegbuzie, 2004; Creswell, 2009; Guthrie, 2010), a mixed methods approach is especially useful for the complex, often interdisciplinary problems being explored in social science research (Creswell, 2009). In this research, which brings aspects of social sciences and biophysical sciences together, the use of qualitative (i.e., semi-structured interviews, document analysis) and quantitative data collection methods (e.g., vegetation inventories, stream temperature measurements) was a necessity. These methods are outlined in the following subsections.

3.4.1 Collection of Data for the Assessment of the Training Program

Data collection pertaining to the assessment of the training program in relation to social-ecological resilience entailed conducting semi-structured interviews (Gillham, 2000) with individuals involved in the development of the training program and requesting program materials for document analysis (Hancock & Algozzine, 2011). Both means of data collection are described here in detail. In addition, websites, presentations, and personal communications with a key informant were drawn on for information regarding the history and evolution of the program. A detailed breakdown of the data sources used is presented in Appendix A. Before any data was collected, an application was made to, and approved by, the Brock University Research Ethics Board (REB) for the involvement of human participants (Appendix B).

Semi-structured interviews were chosen as an ideal method of data collection for this research as they typically yield very detailed information (Guthrie, 2010; Walliman, 2011). Semi-structured interviews allow a researcher to use prompts and probes to clarify answers and encourage interviewees to provide additional insights (Gillham, 2000; Berg, 2004). Prompts help ensure that the important elements of an interview are covered and that interviews are comparable, this is particularly important when it comes to analyzing the data (Gillham, 2000; Guthrie, 2010). For these reasons, semi-structured interviews were more appropriate as a means of data collection than an alternative such as surveys which typically do not allow for the same level of detail, clarity, and flexibility in responses (Walliman, 2011). Although participant observation (DeWalt & DeWalt, 2011) and direct observation (Guest et al., 2013) are two alternative methods of data collection that could have potentially provided a more detailed, intimate understanding of the training program, a limitation of this study is that the timing of the workshops was not congruent with the timelines for the completion of this study.

The interview guide (Appendix C) developed for this aspect of the research was based on the assessment framework (Table 3.1) and included questions focusing on what the program teaches trainees about the five phases of ecological restoration process and prompts derived from the principles. Prior to conducting interviews with program developers using the interview guide, a pilot test was undertaken. Undertaking a pilot test allows a researcher to identify questions that are ambiguous, misleading, or that elicit responses that are uninterpretable or unusable for any reason (Leedy & Ormrod, 2013). By finding these deficiencies in a data collection instrument before beginning data collection, a researcher can make the necessary revisions and ensure that the instrument has validity (Leedy & Ormrod, 2013).

An individual with knowledge about the program and its development was identified for the pilot test by the key informant. A modified invitation was sent by e-mail to the individual explaining the pilot test and inquiring about willingness to participate. Upon expression of interest, a description of the research and a consent form were sent to the individual to review and a time and location were arranged for the pilot test. The same procedure planned for conducting semi-structured interviews with program developers was used for the pilot test with the addition of an explanation of the pilot test upfront and a request at the conclusion of the interview for feedback on the documents, interview questions, and the general interview procedure. Based on the outcomes of the pilot test, minor revisions were made to the interview questions and prompts to enhance clarity and more effectively elicit the information sought from interviewees.

Following the completion of the pilot test and minor revisions, invitations to participate in the study were sent to potential participants. Due to the fact that a list of all of the organizations and individuals involved in the development of the program was not publicly available, the key informant was instrumental in identifying potential participants for this stage of the study. All seven potential participants were contacted by e-mail and invited to participate in the study using the contact information provided by the key informant. Interested individuals received a follow-up e-mail with a more detailed explanation of the study and its purpose, a description of what participation would entail, and a consent form (Appendix D) to review.

Potential participants who had not responded to the initial e-mail within one week received a second e-mail as a reminder of the opportunity to participate in the study. If no response had been received two weeks after the initial e-mail was sent, an attempt was made to invite the potential participant over the phone. When the potential participant could not be reached, a brief phone message was left in which contact information was provided and reference to the e-mails was made. A detailed record of the attempts made to contact potential participants was kept in an Excel spreadsheet. Six individuals agreed to participate and one declined the invitation resulting in a response rate of 86%.

For those who agreed to participate, interviews were arranged at a mutually convenient time and location. By request from the interviewees, several interviews were conducted over the phone rather than in person. Prior to the start of the interview, participants had time to review the consent form explaining what is involved in the study, the voluntary nature of participation, potential benefits and risks, and details pertaining to confidentiality and the publication of results. Two copies of the consent form were signed before the interviews began, one for the participant to keep and one for the researcher. In the cases where interviews were conducted over the phone, signed consent forms were sent electronically.

All interviews were recorded using an audio recorder. Using an audio recorder allows a researcher to have a complete account of the interview without compromising the flow of the interview (Gillham, 2000). Notes made during the interview were for use in that specific interview and were not included in the analysis of the transcript. At the conclusion of the interview, participants were reminded that they would have the opportunity to review their interview transcript and raise any questions or concerns. Participants were also informed in the consent form that as a condition of the ethics clearance granted by the Brock University REB for this research, once they approved the use of their interview transcript by signing an interview transcript release form (Appendix E), their name would be removed from their data and only general descriptors of their role or position and organization would be used in any written or oral communication of the results.

The second aspect of data collection related to Objective Two was the acquisition of training program materials for qualitative document analysis (Hancock & Algozzine, 2011). Document analysis refers to a "systematic procedure for reviewing or evaluating documents...to elicit meaning, gain understanding, and develop empirical knowledge" (Bowen, 2009, p. 27). A number of advantages are associated with document analysis as a research method including cost-effectiveness, lack of obtrusiveness and reactivity, stability of the data source, and exactness of information (Merriam, 1988; Yin, 1994; Bowen, 2009). Document analysis was particularly useful for this research because the training program manual, the document being examined and interpreted in this case, covers all of the content trainees are exposed to without relying on interviewees' memory of the lessons in each workshop. Accordingly, the document provided an additional source of evidence required for triangulation (Berg, 2004). A request was made to the key informant for access to the training program manual. Upon signing a formal agreement with TUC, use of the copyrighted material for research purposes was granted and a hardcopy of the most recent training manual was received.

3.4.2 Collection of Data for the Evaluation of Restoration Initiatives

Data collection with regard to the evaluation of restoration initiatives informed by the training program involved conducting semi-structured interviews with past trainees, obtaining secondary data where possible, and completing site visits for the collection of primary data in the absence of available secondary data. Publically available information and personal observations were also drawn on to supplement descriptions of the initiatives (see Appendix A for a detailed list of all data sources used). The semi-structured interviews were conducted in the same manner for all of the restoration initiatives and as such, they are discussed together. Conversely, because the data collected related to ecological outcomes were unique to each initiative, the specific data collection procedures are described by initiative in separate subsections and associated appendices.

Semi-structured interviews were chosen as the method for eliciting information on restoration process and social outcomes due to the detailed information they typically provide, the freedom they offer the interviewer to prompt or probe an interviewee for further details or clarification on specific details, and the fact that the degree of structure is sufficient to allow for comparisons to be made between interviews (Gillham, 2000; Guthrie, 2010). The interview guide (Appendix F), developed based on the evaluation framework, included questions asking about what was involved in the five phases of ecological restoration process and what, if any, social outcomes of the restoration initiative had been observed. Prompts were derived from the principles and were intended to encourage interviewees to provide additional details.

Before data collection began, the data collection instrument and procedure were pilot tested. The key informant identified and provided the contact information for an individual who had led the planning and implementation of a restoration initiative and the same steps outlined in section 3.4.1 were followed to carry out the pilot test. Piloting the interview guide helped determine whether the questions, prompts, and/or procedure needed to be refined. In addition to testing out the interview guide, the pilot test also involved going through the process of creating a site visit plan including determining the kind of data required and the protocols necessary for obtaining those data.

With the necessary minor revisions made to the data collection instrument, potential participants were invited to participate in the study. Potential participants were past trainees of the training program who had: (1) completed all six of the workshops; (2) led or were extensively involved in a restoration initiative that they self-identified as being informed by the training program; and (3) indicated a willingness to be contacted for research purposes. A list of potential participants and their contact information was provided by the key informant from a TUC database of past trainees. All four of the potential participants identified were contacted and invited to participate in the study using the same protocol outlined in section 3.4.1. Three of the four potential participants agreed to participate resulting in a response rate of 75%.

Interviews with individuals who were willing to participate were arranged at a mutually agreeable time and location. Two interviews were conducted in person while the remaining interview was conducted over the phone at the request of the interviewee. As with the program developer interviews, participants read the consent form (Appendix G) and signed two copies before interviews began. For the interview conducted over the phone, an electronic copy of the signed consent form was received by e-mail prior to the interview. Each interview was recorded using an audio recorder and participants were informed that they would have the opportunity to review the interview transcript prior to any analysis beginning. Participants were notified in the consent form that after signing an interview transcript release form (Appendix E), their name would be removed from their data and only general descriptors of roles or positions and organization descriptors would be used in association with their data.

While the semi-structured interviews elicited information pertinent to the evaluation of restoration initiative process and social outcomes, available secondary data were obtained and site visits were carried out to collect data on ecological outcomes. The decision to delimit the study to measure ecological outcomes in the field in the case where secondary data were not available, and not social outcomes, was based on the fact that ecological restoration is the main focus of this study. Evaluating social outcomes in the field, while also important, was beyond the scope of the study. Furthermore, the decision to have social outcomes self-reported was also based on the idea that the individuals extensively involved in the initiatives were in the best position to evaluate those outcomes (Bennett, 2016).

Ecological outcomes were considered in terms of short-term results/products and longer-term effects (Plummer et al., 2014c) in acknowledgement of the lag that is frequently experienced between implementation and the realisation of the full range of restoration outcomes (Clewell & Aronson, 2013). For the purpose of this research, results/products relate to changes in fast variables typically at smaller scales and are therefore more immediately apparent. For example, installing a habitat structure such as a pallet cover structure can provide enhanced in-stream habitat as soon as the structure is installed (Heaton et al., 2002). On the other hand, effects are associated with slower variables often operating at larger scales. As an example, it may take decades for trees planted in the riparian area to provide woody debris to the stream (Beechie et al., 2010).

The distinction between results/products and effects is noteworthy as it represents a limitation associated with the empirical portion of the research. The empirical portion of this research was restricted to outcomes associated with fast variables that could be evaluated at the site scale, within the timeframe for this study, and with the available resources. Moreover, the outcomes that could be observed and evaluated were limited by the fact that the restoration initiatives were either only recently completed or are ongoing. While outcomes associated with slow variables and those that must be evaluated at scales larger than the site scale are beyond the scope of this research, it should be noted that there are existing frameworks that can assist in understanding what the likely outcomes of restoration activities may look like (cause-response relationship) at different scales (see for example Frissell et al., 1986; Imhof et al., 1996). Despite the empirical evaluation of effects being beyond the spatial and temporal scope of this research, these outcomes and their evaluation are addressed in Chapter Six and Appendix H in terms of future recommendations for each site.

Although data collection was tailored to the specific context of each initiative and as such, employed different methods, the same decision-making process was followed for each initiative and each likely outcome to determine what data were necessary to collect and the appropriate methods to use. This process is detailed in Figure 3.1. The decision-making process was contingent on the results from trainee interviews and secondary data. These results and general descriptions of each restoration initiative are presented in sections 5.2, 5.3, and 5.4. As previously mentioned, outcomes for which data could not reasonably be collected as part of this study or for which there was no baseline data for comparison, represent a limitation of this study and are discussed in Chapter Six and Appendix H.

The following subsections describe the specific data collection methods employed for each restoration initiative as determined by following the steps of the decision-making process outlined in Figure 3.1 (see sections 5.2, 5.3, and 5.4 for context on each initiative). All field work was completed in May and June 2016.

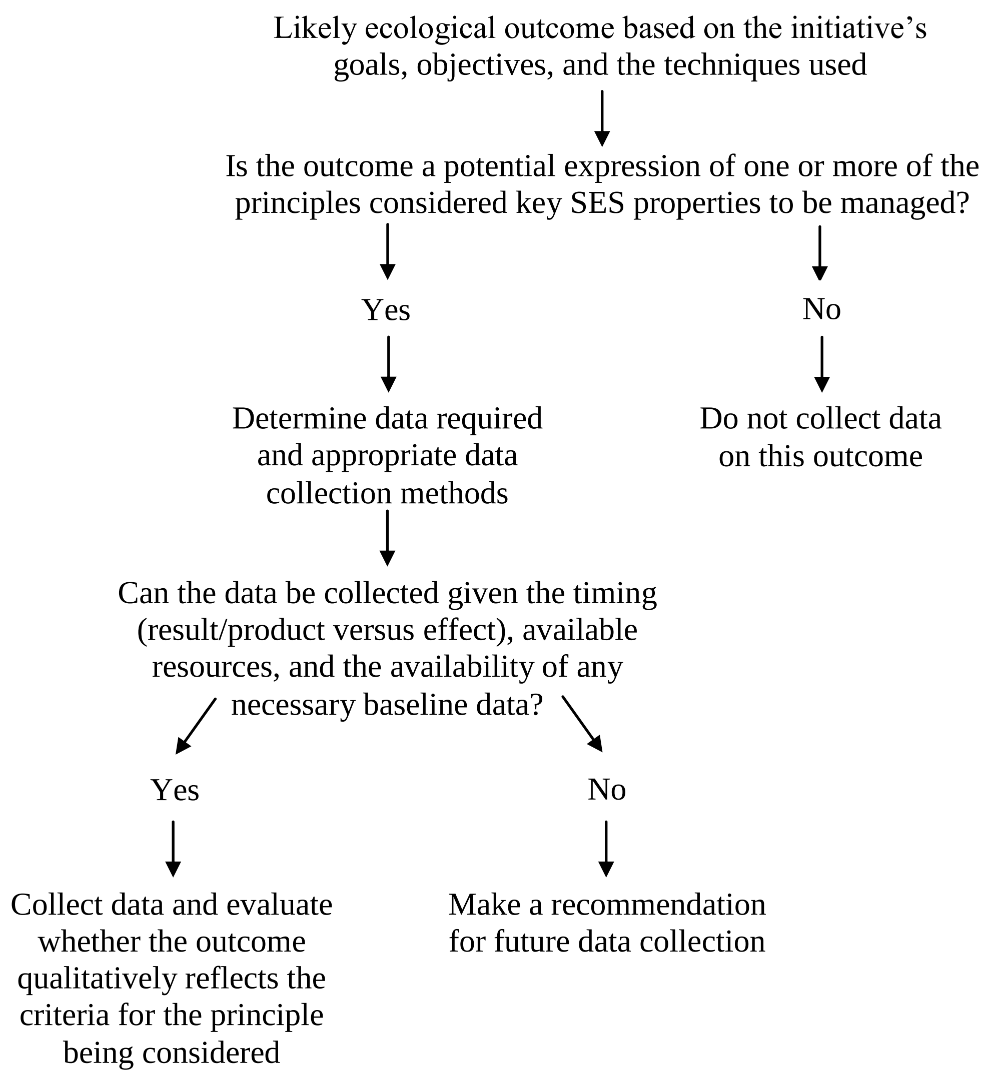

Figure 3.1 Decision-making process for determining data needs and collection methods for evaluating ecological outcomes

3.4.2.1 Restoration Initiative One (RI1)

Woody Vegetation Inventories

The restoration area woody vegetation inventory began with establishing a quadrat. A quadrat is a two-dimensional shape delimiting an area for a purpose such as conducting a vegetation inventory or estimating vegetation cover (Cox, 1990). The size and shape of a quadrat within a study site can be established randomly, regularly, or subjectively (Bainbridge, 2007). The decision was made to use a quadrat over other sample units, transects and plotless sampling methods (Bainbridge, 2007) for example, because the dimensions of the quadrat could be established so that all of the planted species were included in the inventory and could be compared to inventory results from a quadrat of equal size in the reference area.

After visually observing the planted area, stakes and measuring tapes were used to measure and delineate a rectangular quadrat (42 m by 22 m) including all of the trees and shrubs planted in fall 2015 as part of the initiative. With the quadrat setup, the woody vegetation inventory began. Only woody species were identified and recorded as part of the inventory as they were the focus of the planting done as part of the restoration initiative. Starting from one corner of the quadrat, each live woody species encountered in the quadrat was assigned a number starting from one, flagged with a piece of flagging tape, and examined for number of stems. A tree or shrub with a stem that forked at or above the surface of the ground was counted as an individual with one stem while stems forking below the surface of the ground were counted separately and totaled for each individual. Woody species were recorded only if their stem(s) fell within the quadrat and if they were live given the difficulty associated with accurately identifying dead trees and shrubs. Woody species with a branch or branches overhanging the quadrat was not counted. The assigned number, species, number of stems, and whether the tree or shrub was planted as part of the initiative were recorded in the field book. After walking the entire quadrat and recording the necessary information for each woody species encountered, a second walk through the quadrat was done to ensure no live woody plants were missed. All of the flagging tape and stakes were removed upon confirming the completion of the inventory.

The first step in conducting the reference area woody vegetation inventory involved using available information to find the approximate location where the female clamp-tipped emeralds (*Somatochlora tenebrosa*) had previously been observed laying eggs. At that location, a quadrat with the same dimensions as the quadrat used in the restoration area woody vegetation inventory was established along the right bank (looking downstream) of the creek. This area was used as a reference because the restoration area was intended to emulate conditions favourable for clamp-tipped emerald habitat. A brief visual inspection of the woody vegetation on both sides of the creek revealed no notable differences in vegetation. As such, the right bank was chosen out of convenience due to it being in closer proximity to the access point from the Bruce Trail. As with the quadrat in the restoration area, the four corners were staked and the perimeter was outlined using measuring tapes.

With the quadrat established, the woody vegetation inventory was conducted following the same procedure used in the restoration area woody vegetation inventory with one additional condition. Woody species included in the inventory had to be at least as large as the smallest plants in the restoration area inventory which happened to be those that had been planted as part of the initiative. This additional qualification was made for two main reasons. First, the large number and small size of seedlings on the forest floor in the reference area would have made it extremely difficult to accurately find, flag, and record every seedling without missing or double counting any and/or trampling seedlings while setting up and moving through the quadrat. Second, many of the seedlings present at the time of the inventory, the overwhelming majority of which were sugar maple (*Acer saccharum*) seedlings, likely will not survive long enough to grow to the size of the planted species in the restoration area given the site conditions and competition. In fact, in their description of sugar maples, Barnes and Wagner (2011, p. 300) explain, "More than 150,000 seedlings per acre commonly occur on the forest floor of favourable sites, but mortality is high in deep shade".

All of the species identified in the two vegetation inventories were subsequently researched to collect information regarding the tolerances of the species to different disturbances and pests and average height, growth rates, and life spans. Effort was made to find sources of information relevant to the region in which the inventories were conducted or regions with similar conditions.

3.4.2.2 Restoration Initiative Two (RI2)

Woody Vegetation Inventories

As with the site visit for RI1, two vegetation inventories were conducted for RI2, one in the restoration reach and one in the reference reach. In the restoration reach, two wooden stakes on each bank were still in place marking the areas where planting occurred in fall 2015. These stakes were utilized to delineate the boundary of the quadrat parallel to the channel. The other quadrat boundary, running perpendicular to the channel, was defined using the first of three zones described by Stanfield (2013) for examining riparian vegetation communities. According to Stanfield (2013), the first zone includes vegetation within 1.5 m to 10 m from the water. Stanfield's (2013) first zone for examining riparian vegetation communities was selected because it provided a standard measure that included all of the planted woody species but also kept the quadrat size manageable. The same size quadrat was used on both the right and left banks in the restoration and reference reaches.

The woody vegetation inventory began on the right bank in the restoration reach. Using the upstream stake as a starting point, three tape measures were laid on the ground perpendicular to the channel roughly 3 m apart. Each tape measured out 10 m from the water. Starting between the first two tapes, each woody species meeting the following three criteria was identified to species and recorded: (1) the woody species was alive; (2) the stem fell within the boundaries of the quadrat; and (3) the plant was at least the size of the smallest species planted in 2015. The distinction regarding size of the plant was made due to the fact that the herbaceous vegetation within the quadrat was quite tall at the time of the inventory and any woody vegetation smaller than the plantings would have been difficult to see, potentially compromising the accuracy of the inventory. For each tree or shrub encountered, the following information was recorded in the field book, a unique number starting from one, species, number of stems, and whether the tree or shrub had been planted in 2015. Plantings from 2015 were easily identifiable by the coconut fibre mulch mats surrounding the stem(s) of the plants which are used to suppress competition from fast-growing species in the immediate area (Smaill et al., 2011). In addition, some plantings were protected with beaver guards.

Once all of the species in the first 3 m section of the quadrat were identified and recorded, the first tape measure was moved 3 m beyond the third tape measure to delineate another small section of the quadrat. Dividing the quadrat up into smaller sections was done to make the area more manageable to inventory and to reduce the chance of plants being overlooked or double counted. Dividing the quadrat was also done because the channel has natural banks that do not follow a perfectly straight path. Measuring 10 m from the water approximately every 3 m took the natural path of the channel into consideration. This system of inventorying small sections of the quadrat continued until the downstream stake was reached, marking the end of the quadrat. The entire process was subsequently repeated on the left bank of the restoration reach.

In the reference reach, the same inventory procedure was used with one additional step. Whereas the restoration reach had stakes in place to delimit the extent of the quadrat along the water's edge, this boundary had to be measured and flagged on both banks of the reference reach before the inventory could begin. The location of the upstream boundary of the quadrat was based on a description of the reference area provided by Trainee B. Upon completing the reference reach inventories, all flagging tape was removed.

As with the RI1 vegetation inventories, the species identified in the restoration and reference reach inventories for RI2 were researched to collect information on their tolerances and sensitivities to different disturbances and pests, as well as, average height, growth rates, and life span. Sources of information relevant to the region in which the inventories were conducted were sought out where possible.

In-stream Habitat

Underwater video footage has been used in both marine and freshwater research for a number of different purposes including gaining a better understanding of if and how different types of habitat are used (see for example Yellin, 2014; Lindsay & Peterson, 2015; Nagelkerken et al., 2015; Reis-Filho et al., 2016). For this research, underwater video was taken at each of the four habitat structures installed in 2015 using a GoPro Hero 2 camera. At each structure, the camera, mounted on a wooden stake, was placed underwater near the structure and left to record video for the entirety of the battery life. More than one angle or location was captured for each structure and video was recorded on more than one day for three of the four structures. Over seven hours of video was recorded across five visits to the site in May and June 2016. The date, time in, time out, and site number were documented in the field book for each recording. Given that the purpose of the video footage was simply to observe whether fish of any species were using the habitat structures in any way, recording more specific information regarding site conditions such as air and water temperatures, flow, depth, and substrate was not necessary for this study. Furthermore, the dates and times the videos were recorded coincided with other data collection at the site and were, therefore, based on convenience rather than carefully selected criteria.

Temperature

Temperature measurements were taken every hour in the same location for 12 hours starting at 7:30 am on June 3, 2016. This date was selected because the daytime high was forecast to be within a few degrees of the daytime high for the same day the previous year, according to Environment Canada historical records (Government of Canada, 2016a, 2016b). Although daily range, the difference between the daily maximum and daily minimum stream temperature (Simmons et al., 2015), considers a 24-hour period, access to the site for measuring temperatures in 2016 was restricted to daylight hours (CVC, 2016), ruling out the possibility of taking measurements for a full 24-hour period. Despite this fact, the 12-hour period selected for taking stream temperature measurements coincides fairly well with Simmons et al.'s (2015, p. 967) description of daily range as an "integrated measure of change in temperature at one location over time (typically from about sunrise to late afternoon)".

Measurements were taken using a Hanna HI 991300 waterproof temperature meter in the same reach where temperature was recorded by a Credit Valley Conservation (CVC) data logger in previous years. For each reading, the probe was lowered into the main flow of the river (Stanfield, 2013) for at least two minutes before the reading was to be taken in order to allow ample time for the temperature to stabilize. Hourly air and water temperatures for 2014 and 2015 were requested and received from CVC.

3.4.2.3 Restoration Initiative Three (RI3)

A five year work plan for the Mill Creek watershed was completed in April 2016 (Wojcicki, 2016). As part of the development of the work plan, all available data including baseline data and data acquired as recently as January 2016 was compiled and incorporated into the document (K. Wojcicki, personal communication, June 6, 2016). Therefore, the work plan represented an excellent source of secondary data, eliminating the need to arrange site visits to collect primary data on private property. More specifically, the data obtained from the work plan included: electrofishing data from 2010, 2011, and 2014; 2015 spawning survey data; 2016 portable passive integrated transponder (PIT) tag antenna survey data; and qualitative descriptions regarding barriers to flow and in-stream habitat. In addition, fish species identified through the various forms of monitoring were investigated to gather information on their thermal tolerances.

3.5 Treatment of Data

3.5.1 Treatment of Data Collected for the Assessment of the Training Program

The first step in treating the data collected for the assessment of the training program was transcribing the interview recordings verbatim. The transcripts were then read through in their entirety and cleaned to remove extra verbal material such as false starts and non-lexical utterances (Elliot, 2005). Cleaning the transcripts was done to make them easier to read and analyze. Transcripts were then sent by e-mail to participants along with an interview transcript release form. Participants had two weeks to review their interview transcript and confirm its accuracy before a reminder e-mail was sent.

After the transcript release forms were signed by the participants allowing the use of their data, the transcripts, along with the scanned training program manual, were imported into NVivo 10 (QSR International) and read through to familiarize the researcher with the content. NVivo is one example of computer assisted qualitative data analysis software (CAQDAS) available to researchers to assist in analyzing large amounts of data (Guthrie, 2010; Yin, 2014). The use of CAQDAS has several advantages over manual methods. For example, Welsh (2002) contends that using software in the data analysis process can rule out certain instances of human error, improve the ease of, and reduce the time required for, coding text on screen, and allow for different pieces of data to be linked together through electronic memos. NVivo was selected for use in this research because it has all of the functions required for the analysis of the interview transcripts and program manual.

Once in NVivo, content analysis was performed on the training program manual and interview transcripts. Krippendorff (2004, p. 18) describes content analysis as a research technique for “making replicable and valid inferences from texts (or other meaningful matter) to the contexts of their use”. Content analysis involves the “systematic classification process” (Hsieh & Shannon, 2005, p. 1278) of coding. During coding, labels or tags, called codes, are applied to data to assign meaning and help organize the data (Walliman, 2011).

The content analysis in this study was deductive as opposed to inductive (Elo & Kyngäs, 2007) as it utilized a concept-driven coding frame rather than a data-driven coding frame (Schreier, 2012). The development of the coding frame was guided by and reflects the assessment and evaluation frameworks (Table 3.1 and Table 3.3, respectively). Each of Biggs et al.’s (2012) seven principles for building resilience in SES served as a main category, or parent node, in the coding frame while the criteria for judging the presence of the principles (Table 3.2) formed the sub-categories, or child nodes (Jensen & Laurie, 2016). Accordingly, the coding frame makes the assessment and evaluation frameworks operational.

As an extension of the pilot test described in section 3.4.1, trial coding was undertaken to test out the coding procedure and coding frame. Trial coding involves applying a coding frame to part of the material to be analyzed, in this case the data from the pilot interview, using the exact procedure planned for coding (Schreier, 2012). Pilot testing a coding frame is a valuable exercise as it can point out issues such as overlapping categories and awkward phrasing of categories before a significant amount of effort has been put into coding (Schreier, 2012). Based on the trial coding, the coding procedure was adjusted but the coding frame remained the same.

Individual transcripts and sections of the training program manual corresponding with each workshop served as the sampling units as well as the context units (Krippendorff, 2004) for this content analysis. Sampling units refer to units selected for inclusion in an analysis while a context unit sets boundaries on what textual matter within the sampling unit will be considered as context for the recording units (Krippendorff, 2004).

The process of undertaking content analysis began with segmenting each sampling unit into smaller recording units (Krippendorff, 2004), also known as units of coding (Schreier, 2012), via categorical distinction (Krippendorff, 2004). Krippendorf (2013, p. 100) describes recording/coding units as "units that are distinguished for separate description, transcription, recording, or coding" and explains that they are "distinguished to be separately described or categorized". Schreir (2012) contends that segmenting a sampling unit into smaller passages is much more efficient than coding long passages using a large number of categories. Categorical distinction uses membership in a class or category as a means of defining units (Krippendorf, 2013). In this case, recording units were defined according to their membership in a category or phase of the restoration process. Raw data not included in the recording units were kept as part of the context unit.

With the sampling units segmented into recording units, hereafter referred to simply as passages, coding began and was carried out by a single coder. Passages were coded first for phase of restoration process (see Chapter Two, section 2.2.4 for descriptions of the phases). Once all documents had been coded for restoration phase, a coding query was run for each phase starting with problem identification. The parameters on the coding query were set such that all passages coded as relating to problem identification from across the six interview transcripts and the training program workshops were compiled. The resulting list of passages was then reviewed. While reviewing the list, passages expressing similar ideas were grouped together in categories with descriptive titles summarizing what is taught in the training program regarding that specific phase of restoration process. Categories could include passages coded in interview transcripts, the training manual, or both, and some passages fit into more than one category. The iterative process of reviewing the list, assigning passages to a category or categories, and adjusting the descriptive category titles continued until all passages were assigned to at least one category. This process was carried out for all five phases.

Next, passages coded for phase of restoration process were coded for evidence of the principles for building resilience in SES. Simultaneous coding, the application of two or more codes to one passage (Miles et al., 2014), was applied as needed. Simultaneous coding was acceptable in this study because of the interrelated nature of many of the principles (Biggs et al., 2012). Biggs et al. (2012, p.425) highlight this relationship stating, “Although we have attempted to separate individual principles for the sake of analysis and presentation, they are in practice highly interconnected and interdependent”. Attempting to keep codes mutually exclusive would have ignored this relationship and potentially skewed the results by under reporting evidence of some principles.

Passages coded as evidence of a principle were subsequently coded for magnitude. According to Miles et al. (2014), magnitude coding enhances descriptions of data by representing intensity, frequency, direction, presence, or evaluative content. Similarly, Saldaña (2013) explains that magnitude codes can be qualitative, quantitative, and/or nominal indicators and can consist of words, abbreviations, or numbers indicating intensity or frequency. In relation to the assessment of the training program, magnitude is a measure of the importance of a code. The magnitude codes differentiate coded data based on whether the category was emphasized (coded as a 1) or simply mentioned (coded as a 0). Examples of phrases that would warrant a magnitude code of 1 include: “that was stressed right from the first day”; “number one priority”; and “one of the things we really stressed”. Coding for and reporting magnitude was selected as a better way of capturing the importance of principles in relation to the phases than counting number of mentions and reporting frequency. Treating frequency as a measure of importance would have presented an issue with regard to interview transcripts. Because semi-structured interviews allow an interviewer the opportunity to gain clarification when necessary, at times additional questions were asked related to certain principles. The fact that those principles were mentioned more often in the interview does not necessarily mean they were more important, instead the higher frequency could be a result of the need for clarification and more discussion around a certain principle. This concern reflects Holsti’s (1969, p.122) warning that when using frequency, a researcher assumes that the “frequency with which an attribute appears in messages is a valid indicator of concern, focus of attention, intensity, value, importance, and so on”.

After all of the documents had been coded for expressions of the principles and for magnitude, the process was repeated a second time to ensure nothing was missed or accidentally miscoded. A record of all passages coded as evidence of the principles and a rationale for each instance of coding was maintained in an Excel spreadsheet. A separate spreadsheet containing a list of all of the passages coded as magnitude 1 was also kept. These spreadsheets served a purpose similar to decision rules (Schreier, 2012) which are meant to aid coders in determining which code to apply to a passage. The intention of the spreadsheets was to encourage consistency in the assignment of codes.

Once coding for the evidence of principles and magnitude was completed, coding queries (Bryman et al., 2009) were run to compile all of the passages coded as evidence across the phases for each principle starting with ‘maintain diversity and redundancy’. All of the passages for ‘maintain diversity and redundancy’ were reviewed together and passages expressing similar ideas were grouped into categories. The categories summarize what was considered as evidence of the principle. As with the categorization of passages coded for phase of restoration process, categories could include passages coded in interview transcripts, the training manual, or both, and some passages were put in more than one category. The iterative process of reviewing the list of passages, assigning a category or categories, and adjusting the descriptive category titles continued until all passages fit into at least one category. This process was carried out for all seven principles. Categories and examples of the passages within them are provided in Appendix I.

With all of the coding completed, the final step involved running a matrix coding query bringing the results of the content analysis together in a single matrix. Walliman (2011, p. 135) explains that matrix coding queries produce “two-dimensional arrangements of rows and columns” that allow a substantial amount of information to be summarized, displayed, and analyzed. Furthermore, the matrix produced by a matrix coding query can provide “visual cues to patterns in the data” (Mills et al., 2010, p. 193). The query set the principles as rows and the phases as columns in order to display the results in the form of the assessment framework. When done for each sampling unit, this is referred to as a comparative coding sheet which allows a researcher to move from viewing results at the level of passages to the sampling unit (Schreier, 2012). Similarly, when all relevant sampling units are combined, the output is termed a data matrix (Schreir, 2012). The final data matrix provides a holistic view of the evidence and facilitated the process of qualitatively assessing whether and where there is evidence of the principles for building resilience in what the training program teaches about the phases of restoration process.

3.5.2 Treatment of Data Collected for the Evaluation of Restoration Initiatives

Alike the treatment of data regarding the assessment of the training program, the first step in data treatment for the embedded subunits was the verbatim transcription of interview recordings. Following the same procedure detailed in section 3.5.1, transcripts were cleaned to eliminate extra verbal material (Elliot, 2005) and sent in e-mails with transcript release forms to participants. After contact was made and transcript release forms were returned, the interview transcripts were imported into NVivo and read through. Next, deductive content analysis (Elo & Kyngäs, 2007) was performed employing the same concept-driven coding frame (Schreier, 2012) developed based on the assessment and evaluation frameworks and described in section 3.5.1. Trainee interview transcripts served as the sampling and context units for the content analysis and all coding was done by a single coder (Krippendorff, 2004). As with the assessment of the training program, trial coding was also undertaken for the evaluation of the restoration initiatives using the interview transcript from the pilot interview described in section 3.4.2.

Content analysis started with coding passages for phase of restoration process and social outcomes. After this step was completed for all three transcripts, six coding queries, one for each of the five phases plus social outcomes, were run for each embedded subunit. The coding queries compiled all of the passages coded as a specific phase or as social outcomes for a particular subunit. With the results of the coding queries, descriptions of the phases of the restoration process and of the social outcomes were written for all three subunits.

Passages coded as relating to a phase of restoration process were subsequently coded for expressions of the seven principles for building resilience in SES. Only expressions of the four principles considered key attributes of the governance system were coded for passages relating to social outcomes. As with the assessment of the training program, passages coded as reflecting one or more principles were also coded for magnitude, a measure of importance, with a code of 1 indicating that a principle was emphasized while a code of 0 suggested the principle was simply mentioned. For each transcript, the process of coding for evidence of principles and magnitude was repeated to verify that evidence had not been overlooked or miscoded. All passages coded as evidence of principles were added, along with a rationale for each passage, to the Excel spreadsheet described in section 3.5.1. The same was done for passages coded as magnitude 1.

With the coding completed, a series of seven coding queries were run for each subunit. Each coding query compiled all of the passages coded as evidence across the phases and social outcomes for a particular principle. The passages for the principle were reviewed together and passages expressing similar ideas were grouped into categories summarizing what was considered as evidence of that principle. Passages could be placed into more than one category. The list of passages was reviewed, categories were assigned, and descriptive category titles were adjusted until all passages fit into at least one category. This process was undertaken for all seven principles and for all three subunits.

To view the results of the content analysis for a subunit as a whole, a matrix coding query was run. The parameters in the matrix coding query were set with the principles as the rows and phases and outcomes as the columns. The resulting matrix took the form of the evaluation framework showing an overall picture of where evidence of the principles was found across the phases of restoration process and social outcomes, as well as, the magnitude of that evidence. This process was completed for all three subunits.

The treatment of biophysical data pertaining to ecological outcomes of the restoration initiatives being evaluated is described in the following subsections. Ecological outcomes were evaluated with respect to whether or not they qualitatively reflect the criteria for the first three principles listed in the evaluation framework (Table 3.3). These principles constitute what Biggs et al. (2012) consider key SES properties to be managed. The presence or absence of evidence of the principles was recorded in the same evaluation framework with the ecological restoration process and social outcomes information. Where ecological outcomes reflected criteria, the magnitude of that evidence was also evaluated. Due to the fact that ecological outcomes of a restoration initiative can take many years to be fully realized (Clewell & Aronson, 2013), magnitude here refers to the extent to which the ecological outcomes reflected the criteria at the time the data were collected. Magnitude was recorded either as the ecological outcomes fully reflecting the criteria (equivalent to being coded as a 1), or as appearing to be on a trajectory towards reflecting the criteria (equivalent to being coded as a 0). With the addition of the information regarding ecological outcomes to the evaluation frameworks, restoration process and outcomes could be viewed as a whole for each initiative to see where evidence of the principles for building resilience in SES appeared.

3.5.2.1 Restoration Initiative One

Woody Vegetation Inventories

Data from the vegetation inventories were used to create a table (Table 5.1) summarizing and comparing what was found in each inventory. The table contains names of the species identified, total number of individuals and stems for each species, and total number of individuals and stems across all species. The information in the table was then used to calculate and compare Shannon entropy, also called the Shannon-Wiener or Shannon-Weaver index (Spellerberg & Fedor, 2003), and true diversity (Jost, 2006) for both areas.

There are several commonly used indices for measuring species diversity in a community (Morris et al., 2014). Indices are often preferred over the simpler measure of species richness (i.e., the number of species present) because they also take into account the relative abundances of different species and in doing so, provide information about rarity and commonness of species in a community (Beals et al., 2000; Morris et al., 2014). Many diversity indices exist and there is no real consensus on which is most appropriate or informative (Morris et al., 2014). Shannon entropy was selected for use in this research because it accounts for both richness and abundance of the species present and is equally sensitive to rare and abundant species (Magurran, 2004; Morris et al., 2014). For these reasons, Shannon entropy (*H*) is considered by some scholars to be the fairest index and an appropriate choice for general-purpose diversity studies (Jost, 2007; Lucas & Goodman, 2015). *H* is calculated using the following formula:

$$H = -\sum_{\mathrm{i=1}}^{\mathrm{S}} \mathrm{p_i} \ln \mathrm{p_i}$$

where *S* is the total number of species identified in the woody vegetation inventory for the area and p_i is the proportion of individuals found in species *i* (Beals et al., 2000). As richness and evenness increase, the Shannon entropy value increases (Spellman, 2012; Hollister et al., 2014).

Using the resulting values, true diversity was then calculated for each area of equal size to facilitate a meaningful interpretation of the difference in woody plant diversity between the restoration area and the reference area. True diversity is the exponential of the Shannon entropy value (exp(*H*)) (Jost, 2006). Judging the magnitude of difference between the diversity of the two areas requires the calculation of true diversity because Shannon entropy is, according to Jost (2009, online), “highly nonlinear with respect to our intuitive concept of diversity” and as such, often leads to misinterpretation of results. Because any two communities with the same index value have the same diversity, determining the number of equally common species required to produce a particular index value, or the “effective number of species”, provides a linear, easily visualized, and much more intuitive scale to compare the two communities (Jost, 2010). For example, according to the Shannon entropy, a community with a value of 2.2 has the same diversity as a community with 9 equally-common species while a community with a Shannon entropy value of 2.9 has a true diversity of 18 effective species. Although the true diversity of the second community is two times that of the first, the index values on their own would not have reflected this relationship.

Shannon entropy and true diversity values for the two areas were compared to determine whether the species assemblage in the restoration area could be considered diverse relative to the reference area. A diverse species assemblage in the restoration area would represent an expression of the ‘diversity of system components’ criterion for the principle ‘maintain diversity and redundancy’.

Vegetation Structure

The information obtained from researching the growth rates, average life span, and height classes of the species identified in the restoration area woody vegetation inventory was used as a proxy to evaluate the future structural diversity of the area. Using this information, a table (Table 5.3) was created to categorize the species according to several classification systems.

While acknowledging that the rate of growth of a species varies according to site conditions and age, Barnes and Wagner (2011) classify growth rate using the following four categories: slow-growing (less than 30 cm per year); moderately slow-growing (30-60 cm per year); moderately fast-growing (60-90 cm per year); and fast-growing (greater than 90 cm per year). Classification of a species is based on an estimated “height growth rate that young to middle-aged trees would achieve in their representative forest habitat” (Barnes & Wagner, 2011, p. 37). Although Barnes and Wagner’s (2011) growth rate classification was established for describing tree species, it was applied to both trees and shrubs in this research.

The average life span of each of the inventoried woody species was described using Barnes and Wagner’s (2011) longevity classification which estimates the life span of a species in its natural habitat. The four classes are: short-lived (less than 100 years); moderately short-lived (100-150 years); moderately long-lived (150-250 years); and long-lived (over 250 years). Again, the same classification system was applied to trees and shrubs.

Finally, inventoried trees and shrubs were assigned height classes according to Barnes and Wagner’s (2011) tree height classes and Daigle and Havinga’s (1996) shrub sizes. The species were labelled small (up to 1.5 m for shrubs and up to 10 m for trees), medium-sized (1.6 m – 3 m for shrubs and up to 25 m for trees), or large (3.1 m – 6+ m for shrubs and over 25 m for trees). For shrub species sometimes considered small trees, both shrub and tree classifications were included.

The table was reviewed for the presence of a mix of growth rates, life spans, and heights which suggests that the planted area is on a trajectory towards exhibiting diversity in terms of vertical structure and age structure. Moreover, it would represent evidence of the ‘diversity of system components’ criterion for the principle ‘maintain diversity and redundancy’. It is important to note, however, that age structure and vertical stratification of the restoration area would need to be assessed in the future as the information presented in the table reflects the potential of the species inventoried, not a guaranteed outcome.

Species' Tolerances
The information regarding species' tolerances to different disturbances was organized in Appendix J and Table 5.4. Appendix J provides a detailed examination of which disturbances and pests different species are tolerant of or resistant to and intolerant of or susceptible to. Table 5.4 presents the percentage of species in each area that tolerate the disturbances and pests considered. The disturbances and generalist insect pests (Angelo, 2013) considered included drought, flooding, wind, ice storms, shade, browsing, heat, fire, gypsy moth, and Asian longhorned beetle. Generalist insect pests were selected from the list of forest pests on the Ontario Invading Species Awareness Program website (www.invadingspecies.com). Host-specific pests and diseases were not considered because the fact that they are selective with regard to a host means that only a certain species or genus would potentially be weakened, damaged, or killed by the pest or disease (Angelo, 2013). Therefore, as long as the vegetation in an area is not comprised of only one species or plants from one genus, the other species would likely persist in the event of an outbreak.

No generally applicable method exists to determine how much response diversity is 'enough' as the answer is case dependent (Benson, 2009; Biggs et al., 2012). For this study, response diversity in the restoration area was considered relative to response diversity in the reference area. Table 5.4 facilitated the evaluation of response diversity by showing the percentage of species in the restoration area able to tolerate each of the disturbances and pests relative to the same percentages calculated for the reference area. Based on this comparison, a determination was made regarding whether or not the degree of response diversity in the restoration area is sufficient to be considered evidence of the 'response diversity' criterion for the principle 'maintain diversity and redundancy'. As the information presented in Appendix J and Table 5.4 reflects the average or typical response of the species to the named disturbances and pests, future evaluations of actual responses would be required to determine whether the restoration area truly exhibits response diversity.

3.5.2.2 Restoration Initiative Two

Woody Vegetation Inventories
The woody vegetation inventory data from the right and left banks were combined to create one species list each for the restoration and references reaches. The next steps in the treatment of the woody vegetation inventory data were the same as the steps outlined for the RI1 vegetation inventories. A table (Table 5.6) was created to summarize and compare what was found in each inventory and for calculating Shannon entropy values and true diversity.

Vegetation Structure
Following the same procedure outlined for RI1, the growth rates, average life spans, and height classes of the species identified in the restoration area woody vegetation inventory

were compiled and categorized according to existing classification systems (Daigle & Havinga, 1996; Barnes & Wagner, 2011). These classifications served as a proxy for evaluating the future structural diversity of the planted area. The summary table (Table 5.8) created using this information was reviewed to determine whether different growth rates, life spans, and heights were represented by the inventoried species. Representation from a variety of categories suggests that the area may be on a trajectory towards exhibiting diversity in vertical structure and age structure and as such, provides evidence of the 'diversity of system components' criterion for the principle 'maintain diversity and redundancy'. As previously mentioned, an assessment of structural diversity would be required in the future given that the information in Table 5.8 refers to the potential of the inventoried species and actual outcomes would depend on many factors that cannot be predicted.

Species' Tolerances
As was done for RI1, inventoried species' tolerances to the same selection of disturbances and generalist insect pests were recorded and presented in Table 5.9 and Appendix K. Response diversity in the restoration reach was subsequently compared to that of the reference reach to determine whether or not the degree of response diversity in the restoration reach is sufficient to be considered evidence of the 'response diversity' criterion for the principle 'maintain diversity and redundancy'. Again, evaluation of actual responses to disturbances and pests would be required in the future to understand whether the species in the restoration reach do in fact demonstrate response diversity.

In-stream Habitat
Video files were downloaded from the camera and viewed one at a time using Windows Media Player. Every appearance of a fish in the frame was recorded including the time it entered and exited the frame, as well as, any additional notes such as the number of fish in the frame (if more than one). In the majority of instances where a fish entered the frame, it was not possible to identify the fish to species with certainty due to issues with clarity, distance from the camera, and the speed at which the fish passed through the frame. Once all of the files had been viewed, a table (Table 5.10) was created summarizing which of the habitat structures fish had been seen utilizing. The presence of fish at one or more habitat structures would indicate that habitat structures installed to increase habitat availability and diversity are in fact serving that purpose and by doing so, represent evidence of the 'diversity of system components' criterion for the principle 'maintain diversity and redundancy'.

Temperature
With the stream temperature data for June 3, 2014, 2015, and 2016, the temperature ranges (maximum temperature – minimum temperature) and average hourly rates of change (change in temperature/change in time) were calculated for the 12-hour period from 7:30 am to 7:30 pm. Maximum air temperatures for the same 12-hour period were also determined. The ranges and hourly rates of change from 2014 and 2015 were compared to 2016 to determine whether an increase, decrease, or no change has been experienced. A decrease in the range and hourly rate of change from 2014 and 2015 to 2016 would be considered an early sign of the silt traps and riparian plantings

contributing to the function of lowering stream temperatures and in doing so, providing evidence of the 'functional redundancy' criterion for the principle 'maintain diversity and redundancy'.

3.5.2.3 Restoration Initiative Three

Fish Species Diversity and Response Diversity

Direct comparisons regarding the fish community observed in Mill Creek watershed between years could not be made due to differences in the monitoring locations and methods used (e.g., electrofishing, spawning surveys, portable PIT tag antenna surveys). Rather, the fish monitoring data were reviewed collectively to qualitatively evaluate fish species diversity and response diversity (i.e., thermal tolerance). A change in species diversity and response diversity to include a coldwater species (Holm et al., 2010) or community would be considered evidence of the 'diversity of system components' and 'response diversity' criteria for the principle 'maintain diversity and redundancy'.

In-stream Habitat Diversity

Drawing on qualitative descriptions of the availability of brook trout (*Salvelinus fontinalis*) habitat in the Mill Creek watershed in 2008, accounts of the restoration work done in Emerson Creek in 2015, and the results of 2015 spawning surveys and 2016 portable PIT tag antenna surveys, consideration was given to whether in-stream habitat diversity has been improved. The addition of habitat that was not previously available and/or the enhancement of existing habitat would suggest greater in-stream habitat diversity and would be considered evidence of the 'diversity of system components' criterion for the principle 'maintain diversity and redundancy'.

Barriers to Flow

The information available on presence or absence of barriers to flow was reviewed to determine whether beaver bafflers installed in July 2010 were successful in discouraging beavers from damming the channel again. No signs of new beaver dams would indicate that connectivity between upstream and downstream areas has been maintained, evidence of the principle 'manage connectivity'.

3.5.2.4 Cross-case Analysis

The final step was to bring the evaluation frameworks for the embedded subunits together and consider all of the information collectively. As part of this step, analysis of case study data can take many forms, but a commonly cited starting point is reviewing the information to see if any patterns emerge (Gagnon, 2010; Schreier, 2012; Yin, 2014). Gagnon (2010, p. 76) refers to this process as listening to the data to see "whether evidence from different sources converges towards similar conclusions". Given that this research uses an exploratory case study design, research propositions were not defined at the outset of the research as is done for descriptive and explanatory case studies (Baxter & Jack, 2008). Accordingly, undertaking the predictive type of pattern matching Yin (2014) advocates, where the aim is to support or refute research propositions, was not possible for this study. Rather, Rowley (2002, p. 24) suggests an alternative analytic strategy for exploratory case studies involving the development of a descriptive framework in which “sections reflecting the themes in the case study are developed and evidence is gathered within relevant themes, and analysed and compared in these categories”. In line with Rowley’s (2002) suggested analytic strategy, a data matrix (Table 5.14) was created bringing together all of the evidence for the three subunits. Visually displaying the results of the analysis of the individual subunits in a single data matrix facilitated the qualitative process of identifying patterns and discrepancies among the subunits. Additionally, this data matrix was useful in considering the results of the evaluation of restoration initiatives in relation to the assessment of the training program.

Chapter Four: Assessment of the Training Program

4.1 Introduction

This chapter presents the findings from the assessment of the Stream Rehabilitation, From Form to Function Training Program (Objective Two). The assessment was guided by the conceptual framework for building resilience in ecological restoration (see Figure 2.1; Objective One). The two aspects of the conceptual framework relating to Objective Two (i.e., phases of ecological restoration process and principles for building resilience in SES) were operationalized through the development of an assessment framework (see Table 3.1). The framework guided the data collection and analysis regarding the assessment of the training program as described in Chapter Three and for which the findings are presented in this chapter.

The sources of data considered in the assessment of the training program include transcripts from semi-structured interviews with six individuals involved in the development of the program at different stages, as well as the most recent version of the manual given to trainees in the program. Content analysis was undertaken on both of these sources of data. Passages were coded first for phase of restoration process and then for evidence of principles for building resilience in SES (see Chapter Three for a full description of data analysis). In addition, publically available information and personal communications with a key informant were drawn on for information regarding the history and evolution of the program (see Appendix A for a detailed breakdown of the data sources used).

The following sections of this chapter provide an overview of the training program and describe the curriculum in relation to the five general phases of restoration process. Findings from the analysis of the training program in terms of the principles for building resilience in SES are then presented followed by a discussion of key findings from the assessment.

4.2 An Overview of Stream Rehabilitation, From Form to Function

The Stream Rehabilitation, From Form to Function Training Program (formerly Aquatic Renewal Stream Restoration Training Program) was developed over several years in response to renewed interest in stream stewardship in Ontario (Imhof & FitzGibbon, 2014). Aquatic renewal, the "conservation and rehabilitation of healthy and functional watersheds, streams, and their corridors by community groups with training and the assistance of professionals" (Imhof & FitzGibbon, 2014, online), was first introduced as a strategy in the 2006 Grand River Fisheries Management Plan (J. Imhof, personal communication, May 5, 2015). In the following years, the Ontario Ministry of Natural Resources and Forestry (MNRF) Stewardship Coordinators for the former Waterloo and Wellington Stewardship Councils recognized that the volunteer groups they were working with were lacking the necessary knowledge and training to develop and implement aquatic renewal projects. Furthermore, the Stewardship Coordinators hoped that the individuals involved in pioneering stream rehabilitation in Ontario in the preceding decades who were retiring or otherwise not involved in the field anymore could pass their knowledge on (J. Imhof, personal communication, May 5, 2015). In response to the need to train the next generation of watershed stewards, the Stewardship Coordinators began holding training sessions on a small scale to build capacity and to teach volunteer groups when their actions could actually result in more harm than good. These training sessions focused on teaching volunteer groups how to do basic assessments and strongly encouraged partnership arrangements with experts that would not only save experts' time but also help identify solvable problems by volunteer groups.

Following the initial training sessions, the Stewardship Coordinators brought in the Brant Stewardship Resource Network and updated the existing MNRF stream restoration manual to provide materials that complemented systematic instruction through associated workshops. Two series of workshops were launched in 2009/2010 with the intent of providing a background on the basics of stream rehabilitation theory and practice (TUC, 2015b). Initially designed for volunteers, the workshops also attracted young professionals starting out in the field. With a broader audience than anticipated, the Stewardship Coordinators acknowledged a need to move away from strictly volunteer focused training. In order to do this, the workshops subsequently gave way to a collaborative effort involving a consortium of conservation organizations and individuals, led by TUC with funding from a Canada-Ontario Agreement grant, to develop a formal training program (Imhof, 2010). These efforts began in earnest in 2010 and by 2014, all six workshops were complete and had undergone revisions based on feedback from trainees (Mellors, 2012; J. Imhof, personal communication, May 5, 2015).

Led by TUC staff and occasional guest instructors, the training program in its present form consists of six workshops that build on each other and include class presentations, a field trip, a group practicum, a homework assignment, and discussions with instructors and peers (TUC, 2015b). Workshop topics and training objectives are listed in Table 4.1. The workshops are designed to, "formalize the theory, practice and application of watershed and stream assessment and rehabilitation and to train a new generation of individuals, organizations and community groups who will promote watershed, stream and stream corridor rehabilitation" (TUC, 2015b, p. 1). Although the program has undergone revisions over the years, the same basic focus on providing community groups with an understanding of streams and stream rehabilitation to aid them in their efforts to be effective stewards of their local watershed has remained throughout.

Table 4.1 Stream Rehabilitation, From Form to Function Training Program workshops and training objectives (TUC, 2015b)

Workshop 1 – Creating the context: watershed and stream systems
- Provide an understanding of watershed/river systems

Workshop 2 – Understanding and assessing the system
- Provide an understanding and introduction to assessment and monitoring approaches

Workshop 3 – Diagnosing the problem and developing a plan
- Provide an understanding of how to determine key issues and how to address them
- Provide an understanding of what community groups can reasonably achieve, so as to manage their expectations

Workshop 4 – Linking solutions to the problems
- Demonstrate how to determine appropriate actions and how to implement them
- Practice developing practical on-the-ground projects

Workshop 5 – Project planning, development and managing the cookbook
- Demonstrate how to determine appropriate actions and how to implement them
- Practice developing practical on-the-ground projects

Workshop 6 – Applying a strategic approach and introduction to large-scale rehabilitation
- Demonstrate how to develop strategic plans and how to implement them
- Demonstrate how to assess and determine success
- Demonstrate how to promote and improve programs

4.3 Stream Rehabilitation, From Form to Function and the Five Phases of Restoration Process

This section communicates what is taught in the training program about the five general phases of restoration process as uncovered through performing content analysis on interview transcripts and the training program manual. The total number of passages coded for each phase is presented in Table 4.2 and broken down by number of coded passages in the training manual, each workshop in the manual, and interviews. In following the content analysis procedure outlined in Chapter Three, passages expressing similar ideas were grouped together in categories describing how the course covers that phase of the restoration process. Results, the categories and the number of passages grouped within them, are presented in the following sub-sections in accordance with each phase of the restoration process.

Table 4.2 Number of passages coded as each phase of the restoration process

	Training program manual								
Phase of restoration process	W1	W2	W3	W4	W5	W6	Total	Interviews	Total
Problem identification	7	33	16	45	3	13	117	43	160
Defining goals and objectives	7	6	14	21	9	3	60	34	94
Designing a restoration plan	13	8	32	63	27	4	147	42	189
Implementation	0	4	11	6	16	2	39	30	69
Monitoring and evaluation	0	10	11	1	7	0	28	48	76

4.3.1 Problem Identification and Definition

Problem identification and definition is the first phase of the restoration process. This phase involves determining whether, and where, a problem exists in the system and coming to an understanding of the cause or causes of the problem. Of the five phases of the restoration process, the second greatest number of passages were coded as problem identification (see Table 4.2). Passages coded as problem identification occur throughout all six of the workshops but are concentrated most heavily within workshops two (33), three (16), and four (44) focusing on assessing the system, diagnosing the problem, and linking solutions to problems, respectively. The prevalence of passages in the manual coded as problem identification supports the statement by Program Developer D that, "there's a huge investment in this program in identifying challenges".

In both the training program manual and interviews with program developers, passages coded as problem identification were grouped into a number of categories. The category with the greatest number of coded passages in it describes the types of problems that may be identified in a watershed (39). The passages in this category provide groupings of possible problems that may be seen in a watershed (e.g., flow barriers, water quality, fish passage, floodplain connectivity) and describe specific examples of problems (e.g., excessive erosion, flow regime modification, chemical contamination, native fish species loss). The program also focuses a great deal of attention on understanding the difference between causes and effects or symptoms of a problem and how to get at the root cause(s) (31). For example, Program Developer D stated, "...first they're taught to identify what the problem is, what they see and then to identify whether or not that's a cause or an effect. You know, whether it's a symptom or an actual problem". Furthermore, trainees are encouraged to involve professionals with relevant and advanced expertise when problems become too complex for their group and to understand where that threshold is (31).

Categories with fewer than 30 coded passages include those that teach trainees to: recognize that streams are not static and understand how to distinguish between natural change and change that is indicative of a problem (23); understand how watersheds in general, and their specific watershed, function before attempting to identify problems (13); acknowledge that the way in which problems are identified and what is considered a problem depends on the specific context of the watershed (11); assess their system over broad temporal and spatial scales in order to capture natural and unnatural variability (8); identify whether the full life history requirements for different species are present (5); and to gain permission before going on private property to undertake assessments (3).

4.3.2 Defining Goals and Objectives

The second phase of the restoration process involves defining goals and objectives. Goals refer to a desired future condition of the system while objectives are the short and long term activities undertaken in order to achieve those goals. Taken together, the goals and objectives of a project represent the solution(s) to the problem(s) identified in the first phase of the restoration process and as such, they inform the remainder of the process. Similar to problem identification, passages coded as relating to defining goals and objectives occur in all six of the training program workshops. As shown in Table 4.2, over one third of the 60 passages coded as defining goals and objectives are found in workshop 4, which focuses on linking solutions to problems.

Passages coded as relating to defining goals and objectives were grouped into five categories summarizing what is taught about this phase in the training program. Rehabilitating form and function rather than attempting to restore a previous state or for a specific species (33) is the category encompassing the greatest number of coded passages. Trainees are taught that the goal of returning a stream or watershed to a specific historical state is unattainable because of natural and human-caused changes that occurred in the past and that continue to occur today. Instead, "... the goal is to take altered or damaged systems and make them as functional as possible given the existing conditions and features remaining in the system" (Workshop 3). Trainees are also taught that goals and objectives should be negotiated and agreed upon through a collaborative process including stakeholders and experts (26). For example, in response to a question about developing goals and objectives, Program Developer F explained, "You can't train people in this course necessarily on how to negotiate. There's not enough in it to do that but at least they'd be exposed to the fact that, you know, you are going to have to negotiate some of this and there will be compromise". The category with the third highest number of coded passages relates to teaching trainees that goals and objectives must be fit to the specific context (25). This idea is expressed by Program Developer D in discussion around the considerations that go into the definition of goals and objectives, "What does the community want of that area if you're doing rehabilitation work in an area, what is their value of the area and how do you accommodate that?". The final two categories refer to instruction on incorporating social considerations in goals and objectives (9) and revisiting and considering previous plans and goals for the system (4).

4.3.3 Designing a Plan

Following the definition of project goals and objectives, the next phase in the restoration process is designing a plan. Designing a plan involves selecting the specific technique or techniques that fit with the solution(s) to the problem(s) as well as other situational factors such as available resources and expertise. Of the five phases of the restoration process, the greatest number of passages were coded as designing a restoration plan (189). These passages are found across all six of the workshops. However, over one third of the coded passages in the manual occur in workshop four (63) which includes an appendix describing a selection of restoration techniques.

All of the passages coded as designing a restoration plan were grouped into ten categories. Three of the ten categories have over 40 coded passages grouped within each of them. The first category explains that no universal solutions exist; selected techniques must be suited to the specific context and capable of solving the identified problem(s) (57). The manual explains that, "Techniques are not only chosen to solve a problem but also chosen based on stream order, stream type, watershed characteristics and fish community objectives" (Workshop 5). The second category encourages trainees to seek professional help from multiple disciplines and to be as collaborative as possible (45). This idea is evident in many interviewee responses. For example, "We really encouraged partnership" (Program Developer E), "it requires multidisciplinary partnership ... it requires multi-stakeholder partnership" (Program Developer D), "trainees were advised throughout the process to engage the appropriate agencies as early as possible and as often as possible" (Program Developer C), "They were starting to get the picture that they needed other opinion and they needed other expertise" (Program Developer F). The third category provides examples of techniques that can be used to address certain issues (43) (e.g., boulder clusters, fascines, single wing deflectors, stream clean-up days).

Categories four through ten have far fewer coded passages and are as follows: design restoration to work with the natural tendencies of the system to achieve a functional state (22); identify, inform, and engage diverse stakeholders in the watershed (13); several alternative approaches or techniques may be available and in some cases, more than one is required (11); think long-term (9); be open to innovating, experimenting, and making mistakes (5); prioritize and start with small, manageable projects (5); and incorporate social considerations in plans (3).

4.3.4 Implementation

Once the design of the restoration plan is set, implementation is the next step in the restoration process. Implementation involves not only the actual hands-on work, but also all of the planning that goes into successfully running work days such as securing permits, funding, resources, and a volunteer base. With the exception of workshop one, all of the workshops in the training program touch on implementation to some degree. The greatest number of passages coded as implementation are in workshops five (16) and three (11).

The passages coded as implementation were grouped into seven categories reflecting the instruction provided in the training program related to this phase. The first category stresses identifying applicable legislation and obtaining all necessary permits, approvals, and permission (30). This may require engaging with the local Conservation Authority, an agency or agencies at the provincial or federal level, and/or landowners. With regard to legislation and permits, the training manual states, "There are numerous pieces of Provincial and Federal legislation and regulations that are being enforced and it is important to ALWAYS get the appropriate permits" (Workshop 3). The category with the second largest number of coded passages relates to communicating with stakeholders about what is being done, for what reasons, and about progress made (19). Different ways of communicating this information are discussed in the program, one of which is during workdays, "making sure there's a whole explanation of what we're doing and why we're doing the project and what's lacking in the site, what needs to be fixed and why we got to this point and yes, we have permits to do it" (Program Developer F). The third category encourages taking every step to ensure successful implementation but also being willing to adapt if things do not go as planned (12). The rest of the instruction on implementation focuses on: undertaking the necessary planning before starting any hands-on work (9); seeking professional assistance as needed (6); getting volunteers involved and using workdays as an educational tool (5); and understanding the logistics of managing a workday (4).

4.3.5 Monitoring and Evaluation

The final phase of the restoration process involves monitoring and evaluating project outcomes. This phase is important for understanding whether the implementation phase was carried out as planned and how the system is responding. Accordingly, monitoring and evaluation is critical to determining the degree of success of a project. Passages coded as relating to monitoring and evaluation occur in workshops two (10), three (11), four (1), and five (7). No passages in workshops one or six were coded as monitoring and evaluation.

The 76 passages coded as monitoring and evaluation in the program manual and interview transcripts were grouped into eight categories. The category with the greatest number of coded passages explains the importance of sharing monitoring data and outcomes widely (21). This includes sharing monitoring and evaluation information with project partners, approval agencies, landowners, funders, the community, and even interested individuals beyond the watershed through conference presentations. Sharing this information can serve a number of different purposes, "Some of it is totally altruistic where you want to help other people find their own local stream and work on it and others is it builds you credibility in the community which will take you further" (Program Developer E). Instruction on monitoring and evaluation in the training program also focuses on the value of monitoring information feeding back into the restoration plan, the management of the project site, and/or future projects (19). This is clearly described in the manual, "If it did not work, monitoring will give direction on why the desired outcome was not achieved and how to modify the approach in the future" (Workshop 2). Furthermore, trainees are taught to consider whether a restoration plan is achieving, or has achieved, its intended purpose based on the project's goals and objectives (18). This means that in evaluating project outcomes, "You go right back to your goals and objectives of the project and your monitoring and assessment after the fact should meet those goals" (Program Developer D).

The remainder of the instruction on monitoring and evaluation relates to: collecting and comparing pre-intervention and post-intervention metrics or variables over several years (13); acknowledging that system response times will vary based on the techniques used and the timing of disturbances (6); seeking advice and/or mentorship from professionals (5); having a plan for monitoring and evaluating outcomes before starting any work (3); and understanding that monitoring can range from simple observation to complete programs (3).

4.4 Principles for Building Resilience in Social-Ecological Systems

This section presents the findings from the analysis of the training program described in section 4.3 in terms of the principles for building social-ecological resilience (see Table 2.2 for a description of the principles). The results communicate evidence of the principles in what is taught about the phases of restoration process and the importance of each principle in the different phases. Following the coding protocol outlined in section 4.3, passages coded as relating to a phase or phases of the restoration process were considered next in terms of whether they represent an expression of one or more of the principles for building social-ecological resilience. The criteria for assessing the presence of principles in the phases of restoration process are found in Table 3.2. Rather than reporting frequency, as was done in section 4.3 for the phases, this section reports on the expression of principles in terms of magnitude, an assessment of the importance of the code. Passages coded as evidence of a principle were coded according to whether the principle was simply mentioned (coded as 0) or emphasized in the passage (coded as 1) (see Chapter Three for a detailed discussion of the coding procedure).

Table 4.3 provides an overview of the analysis of the training program. The following subsections present the results of the assessment according to each of the respective principles.

Table 4.3 Results of the assessment of the Stream Rehabilitation, From Form to Function Training Program in relation to social-ecological resilience. The degree of magnitude of the principles is conveyed through white boxes (absent), light grey boxes (present), and dark grey boxes (emphasized in at least one instance).

		GENERAL PHASES OF ECOLOGICAL RESTORATION PROCESS				
		Problem identification	Defining goals and objectives	Designing a restoration plan	Implemen-tation	Monitoring and evaluation
PRINCIPLES FOR BUILDING RESILIENCE IN SES	Maintain diversity and redundancy					
	Manage connectivity					
	Manage slow variables and feedbacks					
	Foster CAS thinking					
	Encourage learning and experimentation					
	Broaden participation					
	Promote polycentric governance systems					

4.4.1 Maintain Diversity and Redundancy

Passages coded as evidence of 'maintain diversity and redundancy' are found in all five phases of the restoration process. Moreover, all phases with the exception of the implementation phase contain passages coded as magnitude 1 (emphasized). As an example, during problem identification and while defining goals and objectives, the program manual urges trainees to work with professionals from diverse backgrounds, “the importance of working with professionals and between various disciplines is stressed to improve the ability to understand the issues and possible solutions” (Workshop 3).

Across the phases, evidence of the principle ‘maintain diversity and redundancy’ is summarized by six categories. The category with the most coded passages within it relates to monitoring biodiversity and taking steps to maintain or enhance it (20). One example from the program manual refers to diversity of fish species, “Loss of native fish species (e.g., brook trout) has occurred in many rivers, streams and lakes in the Province of Ontario... Restoring native species begins with determining the cause of the loss and whether this cause has been or can be resolved” (Workshop 4). The second category refers to identifying where and how habitat diversity and redundancy have been lost or reduced and seeking to restore or enhance them (12). This applies to all types of habitat, “one of the principles to sound rehabilitation is ensuring that each species and its community have the elements needed for their entire life cycles from a healthy natural system” (Workshop 1). The third category suggests that individuals and groups with diverse perspectives, values, and knowledge have a stake in the watershed and should be included in the restoration process (11). This was touched on by Program Developer F who explained, “...we tried to get people to realize that there’s a lot of people that have a stake in it whether they want to recognize that or not and what they’re expecting to do may or may not fly with other people in the community”. The remaining three categories each have fewer than 10 coded passages within them and include: achieving desired outcomes may require a combination of techniques used simultaneously or in sequence (5); multidisciplinary and multi-stakeholder partnerships enhance capacity to understand and resolve issues (3); and consider response diversity in plan design (1).

4.4.2 Manage Connectivity

As with ‘maintain diversity and redundancy’, evidence of the principle ‘manage connectivity’ is present across all five phases with passages coded as magnitude 1 in all but the implementation phase. For example, in discussing problem identification, Program Developer E explained the emphasis placed on teaching trainees to understand what an appropriate structure and strength of interactions between system components looks like. Explaining what can be expected in terms of connectivity helps trainees identify what is natural change versus change that may be indicative of a problem, “One of the things we stressed was that erosion, for example, is a natural process...that whole dynamic equilibrium of stream channel change, that was stressed that erosion and sedimentation are natural processes and stream channels will move” (Program Developer E).

Six categories summarize the passages coded as evidence of ‘manage connectivity’, half with over 20 coded passages in each and half with five or fewer coded passages. The category with the greatest number of coded passages refers to understanding how dynamically stable channels function and seeking to restore balance between sediment and flow regimes in degraded channels (42). In the training program, “...the instructors specifically talk about the diagnostic features that you would see if a channel is changing its equilibrium form. You'll be able to identify things that are changing but are things that you would expect in a dynamically stable system" (Program Developer A). The second category relates to analyzing ecological pathways to determine where there may be discontinuities that need to be addressed (30), "Some watersheds, depending on their make-up will naturally have some pathways that are not there. Other watersheds will have broken or lost pathways because of human activities" (Workshop 1). The third category covers the idea of sharing information through a network of relevant stakeholders within and beyond the watershed and seeking input and feedback (22), "Within the partnerships, within the partners, within the community, we very much speak to the need to share information" (Program Developer D). The three minor categories with five or fewer coded passages are: certain situations require reducing connectivity to improve the health of the stream (6); consider the degree of connection desired between the restoration site and the broader landscape (2); and create modularity in the project team by dividing up tasks and distributing the workload (2).

4.4.3 Manage Slow Variables and Feedbacks

With the exception of the implementation phase, evidence of the principle 'manage slow variables and feedbacks' is present in all phases. Passages coded as magnitude 1 are found in the defining goals and objectives and monitoring and evaluation phases. In relation to defining goals and objectives, for example, trainees are encouraged to find solutions that do not introduce or maintain feedbacks that perpetuate undesirable configurations, "We stressed, for example, one thing you want to avoid is starting to armour banks to prevent erosion completely because you're just going to transfer that energy downstream which could cause more problems" (Program Developer E).

The evidence for 'manage slow variables and feedbacks' was grouped into six categories. Monitoring as a specific form of feedback (15) is the category with the greatest number of coded passages. This category encompasses passages that describe how monitoring data should feed back into the management of the restoration site and/or future restoration activities, "we talk about this iterative approach where you do the work, you do the monitoring and assessment and based on that information, figure out whether or not tweaks have to be made" (Program Developer D). The second category refers to selecting restoration techniques to disrupt or dampen undesirable feedbacks (11). For example, "Wing deflectors are one in-stream structure that can be used to re-direct flow away from an eroding bank ... they can also be used to increase meandering and channel narrowing" (Workshop 4). With four coded passages, the third category relates to the fact that hard engineering creates undesirable feedbacks resulting in the need for continuous maintenance. Categories four through six have only one coded passage each. These categories are: actively adjusting channels create a feedback loop maintaining the need for further adjustment (1); understand changes in slow variables over time (1); and design plans based on the full potential of the system as determined by the slow variables (1).

4.4.4 Foster CAS Thinking

All five phases of the restoration process contain evidence of the principle 'foster CAS thinking' and, with the exception of the implementation phase, passages coded as magnitude 1. Discussion around the importance of context in designing a plan provides an example of emphasis being placed on 'fostering CAS thinking', "that was reinforced numerous times, as well as, if it works somewhere, it won't always work everywhere – was another thing that was always focused on" (Program Developer C). Of all of the principles, by far the greatest emphasis is placed on 'foster CAS thinking'.

Passages coded as evidence of this principle were grouped into 11 categories, 2 with over 40 passages within them and the remaining 9 with 31 or fewer passages. With 62 coded passages, the first category highlights the fact that context plays a critical role in each phase of the restoration process, "We kept stressing, don't take that cookbook approach. You know, really go back to the problems and the issues and then try to work on what will solve those" (Program Developer E). The second category consists of coded passages suggesting that plans be designed based on an understanding of past and present conditions at the focal scale and the scales above and below (43). For example, in the program manual it is written that "Understanding the historical changes to the watershed as well as recent and potentially future changes is necessary in order to determine what solutions or treatments to apply to the stream in order to restore function" (Workshop 4).

Categories three through eight each have more than ten passages within them and are as follows: work with the stream's natural tendencies to restore form and function (31); appreciate the complexity of stream systems and encourage an adaptive approach to restoration (26); acknowledge that change and surprise are inevitable and may occur naturally (20); think and plan long-term recognizing that systems display variability over time as well as space and that system response is not always immediate (17); gain an understanding of how the different ecological processes within the system work and how they function together as a whole (15); and consider both ecological and social aspects of the system and how they interact (14). Finally, categories nine through eleven have fewer than ten passages within each of them and include: variability and diversity within a system is natural and beneficial, reducing that variability can have many negative consequences (6); problems may have multiples causes and/or multiple possible solutions and may require the use of a suite of techniques (6); and encourage resilient systems (2).

4.4.5 Encourage Learning and Experimentation

Passages coded as an expression of the principle 'encourage learning and experimentation' are present in each of the five phases of restoration process. In addition, passages coded as magnitude 1 are also in all five phases. One such example related to the monitoring and evaluation phase is found in the program manual in which the relationship between long-term monitoring and learning is described, "One of the greatest learning opportunities is to observe the response of a stream to a design over a period of years" (Workshop 5).

Of the seven categories summarizing passages coded as evidence of the principle 'encourage learning and experimentation', the category with the greatest number of passages concerns explaining the purpose and process of the project to stakeholders and being open to input (19). Included in this category is the following passage from the program manual, "People like to know why and what is planned in a rehabilitation program. Bringing interested people from your organization and others together and discussing how to proceed is an important step" (Workshop 2). The second category relates to establishing mentoring partnerships to facilitate the acquisition of new knowledge and skills (13). As explained by Program Developer C, "...there is no substitute for experience with an expert in the field and mentorship was recommended for the groups". The last of the categories with greater than ten coded passages refers to sharing project monitoring and evaluation information widely (12). As explained in the program manual, "reporting to all those interested is an investment in future projects" (Workshop 5).

The remaining four categories have fewer than ten coded passages each and include: monitor changes over the long-term and recognize that there may be lag time between project completion and outcomes (7); build a community of practice related to stream rehabilitation (5); be willing to make mistakes and learn by doing (3); and be open to innovation and experimental techniques (2).

4.4.6 Broaden Participation

Similar to 'encourage learning and experimentation', evidence of the principle 'broaden participation' is found across the phases of restoration, as are passages coded as magnitude 1. The following passage offers an example of evidence of 'broaden participation' coded as magnitude 1 in relation to designing a restoration plan, "...we're definitely emphasizing [collaboration] I think in every single day of the workshop. I think this is why this kind of training doesn't exist because it's got to be one of the most multidisciplinary things you can do which makes it challenging" (Program Developer D).

Of the seven categories summarizing the passages coded as expressions of the principle 'broaden participation', the category with the most coded passages relates to seeking partnerships with professionals for expert advice and mentorship (48). These partnerships are encouraged for all phases starting with problem identification, "... once you come up to some conclusions that perhaps erosion is excessive in some areas or deposition is excessive then go back to these people that you've sought as mentors and ask them if they could confirm your conclusions" (Program Developer E). With 27 coded passages, the next category refers to engaging the appropriate agencies and individuals to secure permits, approvals, and permissions. For example, the program manual cautions, "Any work will require the approval of the landowner" (Workshop 3) and "It is necessary to understand which, if any, legislation applies to a particular project and what, if any permits are necessary" (Workshop 5). The third category is about identifying and bringing together diverse stakeholders to negotiate project plans (22), "...list the other stakeholders who would be interested or could either benefit from or in another way, perhaps may not be happy with what they're doing, and try to seek those folks out" (Program Developer E).

The final four categories each have fewer than 20 coded passages and include the following: seek information from a variety of sources (18); inform relevant stakeholders of the purpose, status, and outcomes of projects (17); involve experts from a diverse range of disciplines (16); and find opportunities to involve volunteers in projects (10).

4.4.7 Promote Polycentric Governance Systems

Evidence of the principle 'promote polycentric governance systems' is found across all phases of the restoration process with passages coded as magnitude 1 in the designing a restoration plan and implementation phases. For example, in discussion regarding the implementation phase, Program Developer E refers to the importance of engaging with different governing bodies stating, "That was also stressed in the course, that you need to obtain approvals".

Four categories summarize the passages coded as evidence of this principle, two with over ten coded passages within them and two with only one each. The first category stresses that engagement with multiple governing bodies is required to obtain formal approvals and permits as well as formal and informal permission (12). This idea is clearly expressed in the program manual which states, "Permission for work on public properties is required from multiple agencies" (Workshop 2). The second category suggests that project deliberations and decision-making should involve agencies and individuals with various sources of authority and expertise (11), "All projects, involving instream channel or flow modification, need to be reviewed by a professional and approvals will likely be required by environmental/conservation/natural resource agencies" (Workshop 3). The final two categories refer to keeping approval agencies informed on the status of the project (1) and being aware of vertical nesting of applicable legislation (1).

4.5 Discussion of Key Findings

In relation to the results of the assessment of the training program presented in this chapter, this section discusses the key findings in terms of the literature on ecological restoration and social-ecological resilience. Specifically, this section covers three main areas of discussion: (1) what the results say about applying the principles for building resilience in SES to an ecological restoration context; (2) what the results suggest about the approach to restoration taught in the training program; and (3) what the implications of the results are.

4.5.1 Applying Principles for Building Resilience in SES to an Ecological Restoration Context

Ecological restoration scholarship has been referring to restoration that maintains, enhances, or degrades ecological resilience in a variety of ecosystems for several years (see for example Allen et al., 2002; Suding et al., 2004; Palmer et al., 2005; Harris et al., 2006; Seavy et al., 2009). In addition, recognition of the interdependencies between ecological and social systems is growing and scholars are increasingly discussing the need for, and potential benefits of, integrated approaches to restoration (Noss et al., 2006; Choi, 2007; Zellmer & Gunderson, 2008; Egan et al., 2011; Suding, 2011; Perring et al., 2015). The assessment of the training program provided a means of empirically testing the conceptual framework presented in Chapter Two which illustrates how social-ecological resilience and aquatic ecosystem restoration could conceptually be brought together. The results of the assessment show that it is possible to apply Biggs et al.'s (2012) principles for building resilience in SES to an aquatic ecosystem restoration context and in doing so, confirm what is being suggested in the scholarly literature regarding the application of resilience concepts to ecological restoration. In addition, the results demonstrate that this type of approach to restoration can be taught through a training program geared towards individuals from a variety of backgrounds and with a wide range of knowledge. This is important because it represents an example of moving from resilience thinking to resilience practice to train a new generation of watershed stewards.

4.5.2 A Training Program Teaching a New Approach to Aquatic Ecosystem Restoration

The assessment of the training program revealed that with one exception, all of the principles for building resilience in SES are expressed to some degree in what is taught about the five phases of restoration process. These results suggest that the training program responds to the identified need to move away from an oversimplified understanding of stream systems and their restoration (Hobbs & Cramer, 2008) by presenting a different way of thinking about watersheds and stream corridors that reflects the principles for building resilience in SES.

Many of the categories summarizing evidence of the principles in what is taught in the training program directly counter the assumptions underlying approaches to restoration that frequently fail to produce intended results. Notably, two categories related to the principle 'foster CAS thinking' – context plays a critical role in each phase of the restoration process (62) and plans should be designed based on an understanding of past and present conditions at the focal scale and the scales above and below (43) – challenge the assumption that complex systems can be reduced to a point where simplified guiding principles can be applied universally with little understanding or consideration of uncertainty, surprise, interconnections, and temporal and spatial scales (Hilderbrand et al., 2005; Hobbs & Cramer, 2008; Mika et al., 2010). As another example, passages coded as evidence of the principle 'maintain diversity and redundancy' and grouped in the category monitor biodiversity and take steps to maintain or enhance it (20), advise trainees to get to the root cause of a problem rather than fixating on, and attempting to address, only the symptoms of the problem (Hilderbrand et al., 2005).

The extent to which the assessment of the training program revealed evidence of the principles considered key SES properties to be managed and key attributes of the governance system suggests that the training program also answers the call for more integrated approaches to restoration, approaches that take into account social as well as ecological considerations (Zellmer & Gunderson, 2008; Suding, 2011; Naiman, 2013; Perring et al., 2015). As Perring et al. (2015, p. 13) point out, "Although restoration may focus on ecosystems and non-human species, it is primarily a human endeavor, with a range of motivations and goals". As such, Zellmer and Gunderson (2008, p. 894) explain that designers and managers of restoration plans have the difficult task of recognizing "the interplay between, and constraints imposed by, both the sociopolitical and biophysical worlds". The training program confronts this interplay between social and ecological domains described by Zellmer and Gunderson (2008) in what it teaches about each phase of the restoration process.

Although the training program does not explicitly define resilience or describe the specific principles, the results indicate that it teaches trainees about stream corridors, watersheds, and their restoration using an approach that is more reflective of resilience thinking than the kind of thinking described by Hilderbrand et al.'s (2005) myths of restoration or other descriptions of oversimplified approaches to restoration (see for example Lake et al., 2007; Hobbs & Cramer, 2008; Mika et al., 2010). This aligns with the way social-ecological resilience is being used in this research, as a framework or approach to thinking about CAS (Anderies et al., 2006). According to Anderies et al. (2006, online), using social-ecological resilience as a framework for "systematically thinking about the dynamics of SESs ... includes lessons for management and attempts to capture the more general, but not detailed, features of the ways in which many complex systems behave."

In their work, Brand and Jax (2007, online) assert that Anderies et al. (2006) use the concept of resilience as a boundary object, "a term that facilitates communication across disciplinary borders by creating shared vocabulary although the understanding of the parties would differ regarding the precise meaning of the term in question". While critical of this approach for a number of reasons, Brand and Jax (2007) also explain that boundary objects can be very effective communication tools capable of bridging gaps between scientific disciplines and between science and policy. The authors conclude their work stating that "resilience conceived as a boundary object should be designed in a manner to foster interdisciplinary work" and that in this sense "resilience constitutes a vague and malleable concept that is used as a transdisciplinary approach to analyze social-ecological systems" (Brand & Jax, 2007, online). The assessment of the training program suggests that this is the way the program employs the concept of resilience, not as a descriptive ecological concept (Brand & Jax, 2007) but as an approach for understanding and analyzing SES that brings together social and biophysical considerations across multiple disciplines. In doing so, the approach taken by the training program is less about the specific details of resilience and more about introducing trainees to a new way of thinking about, and making sense of, CAS and their restoration.

4.5.3 Implications of the Results

The fact that the assessment of the training program revealed a high degree of reflection of the principles for building resilience in SES in what is taught about the phases of restoration process is very important because it is well known that approaches based on the old way of thinking rarely produce intended outcomes (Hobbs & Norton, 1996; Lake et al., 2007). Approaches to restoration based on the assumptions that stream systems behave in a predictable manner and can be returned to a specific historical state epitomize Hilderbrand et al.'s (2005, online) description of an "over-application of over-simplified concepts to complex systems". These oversimplified approaches are limited in their utility because they do not adequately reflect the complexity and dynamic nature of stream systems (Hilderbrand et al., 2005; Mika et al., 2010). In fact, in some cases they can actually do more harm than good making it crucial to break away from repeating the same mistakes. Taking a new approach that does begin to factor in change, uncertainty, interdependencies, and other characteristics of CAS creates the potential for more successful restoration outcomes at a time when restoration is being looked to as a solution to many of the environmental problems facing society today and in the coming decades (Perring et al., 2015; Suding et al., 2015). This potential may exist not only in terms of aquatic ecosystem restoration, but for other types of restoration and for conservation more broadly.

Over the long-term, as more trainees are taught to understand and relate to their watersheds as CAS, and as more communities get involved with restoration initiatives that are informed by and reflect this way of thinking, it is possible that many of the problems that restoration is charged with solving could be avoided in the first place. Of course, not all issues facing watersheds would be eliminated with a shift in how communities understand and relate to their watershed but limited time and resources could be directed to those issues beyond a community's control.

Chapter Five: Evaluation of Restoration Initiatives Informed by the Training Program

5.1 Introduction

The findings from the evaluation of restoration initiatives informed by the Stream Rehabilitation, From Form to Function Training Program (Objective Three) are presented in this chapter. An evaluation framework (see Table 3.3) was created to operationalize the conceptual framework for building resilience in ecological restoration (see Figure 2.1; Objective One) in order to fulfill Objective Three. The evaluation framework consists of the principles for building resilience, the phases of restoration process, and social and ecological outcomes. As described in Chapter Three, the evaluation framework guided the data collection and analysis for the evaluation of restoration initiatives informed by the training program.

The evaluation of restoration initiatives involved several sources of data including transcripts from semi-structured interviews with three individuals involved in the restoration initiatives, site visits, and secondary data. In addition, publically available information and personal observations were drawn on for information to supplement descriptions of the initiatives (see Appendix A for a list of the data sources used). Transcripts underwent content analysis with passages coded first for phase of restoration process and social outcomes and then for evidence of principles for building resilience in SES (see Table 2.2 for a description of the principles and Table 3.2 for the criteria used to assess the presence of principles). The interview transcripts illuminated the goals and objectives of each initiative which subsequently informed the decision-making process with respect to the methods described in Chapter Three for evaluating ecological outcomes.

The first three sections of this chapter follow the same structure. Each presents the descriptive results from the process of data collection and treatment outlined in Chapter Three starting with a succinct overview of the restoration initiative. The initiative is then described in terms of the five phases of the restoration process as well as its outcomes (ecological and social). Drawing on the descriptive results, evaluative findings follow from the analysis of the restoration initiatives. The evaluative findings from the three restoration initiatives are subsequently brought together in section 5.5 and the cross-case findings are presented. Finally, section 5.6 discusses the key findings from the evaluation.

5.2 Restoration Initiative One

RI1 involves the improvement of habitat for a dragonfly, the clamp-tipped emerald (*Somatochlora tenebrosa*), at Scotsdale Farm located within the Silver Creek Watershed, a subwatershed of the Credit River. The area surrounding Scotsdale Farm has been the focus of restoration efforts (e.g., riparian tree planting) for close to two decades and the property itself, with trout streams and a small dam, has received attention for a number of years from different groups wanting to build on the positive work done in the area. In the past, conservation organizations were unsuccessful in obtaining permission to plant trees at Scotsdale Farm which is owned by Ontario Heritage Trust (OHT). This changed however, with the discovery, made by an entomologist hired by CVC, of a provincially rare dragonfly at Scotsdale Farm. On several occasions in 2011 and 2012, the entomologist identified the presence of a number of adult clamp-tipped emeralds (Frania, 2012). He suggested to Trainee A that the habitat for this dragonfly could be improved by planting trees in a swale to increase water retention which would create a greater source of water for nearby streams and a greater source of food for fish in the streams. Through a collaborative effort including CVC, OHT, and a stewardship organization, a plan was created to plant 150 trees and shrubs in a wet, low-lying area near a perennial stream. The plan was approved in 2014 and the work was completed in fall 2015 with the help of high school students participating in a program run by CVC. While the goal for this project was to improve habitat for the rare dragonfly, Trainee A also saw this project as an opportunity for future work as part of a larger, longer term restoration program at Scotsdale Farm.

5.2.1 Results of Restoration Initiative One

5.2.1.1 Problem Identification

An entomologist hired by CVC was undertaking environmental studies in the Credit River Watershed related to rare dragonflies. As part of his work for CVC, he conducted a study at Scotsdale Farm located in the hamlet of Ballinafad. The property, presently owned by OHT, is open to the public and is comprised mainly of former farmland with several buildings, public trails, streams, and a small dam. Prior to being farmed, the area "would have been fully wooded and it would be a lot wetter" (Trainee A). Trainee A explains that the entomologist "must have got some hint from some previous studies, historical studies that there's something going on that area and other areas so he took a close look there". The study revealed the presence of a provincially rare dragonfly, the clamp-tipped emerald. The entomologist suggested to Trainee A that the habitat for this dragonfly could be improved because the amount of water flowing in the small stream where a female was seen laying eggs appears to vary from year to year with some years having considerably less flow and potentially less available habitat (Frania, 2012). Trainee A subsequently brought this information forward to OHT.

5.2.1.2 Defining Goals and Objectives

Defining the goals and objectives of the project was not done through a formal or extensive process. Rather, Trainee A explains that, "it was just sort of self-evident". The entomologist suggested the goal of improving habitat for the rare dragonfly upon discovering it in a very limited area at Scotsdale Farm and offered the enhancement of water retention capacity in a swale near a stream as an appropriate objective to achieve that goal. The rationale for enhancing the water retention capacity of an area near the stream where a female clamp-tipped emerald was seen laying eggs was to have an additional source contributing water to the stream in times of low flow when habitat availability may otherwise be limited. The area chosen for water retention capacity enhancement is an area believed to have been contributing water to the stream prior to being converted to farmland (Frania, 2012).

5.2.1.3 Designing a Restoration Plan

The general design for the restoration plan was conceived by the entomologist and Trainee A. Together they decided on planting 150 trees as the specific technique used to improve water retention capacity. The location chosen for the planting was a low-lying, wet area roughly 100 m from a nearby perennial stream, “We felt with trees that would become a little bit more wet because a little bit further on there is a running stream. This is an intermittent stream, I guess that we planted and we thought it would help make it full time” (Trainee A). In terms of resources, the initial plan was to “try to get a grant to pay for the trees and then we would advertise it and have a public planting” (Trainee A). However, through conversation with a CVC employee, a partnership was formed in which the project would be funded and carried out through a CVC run program that gets high school students involved in stewardship activities in their community. The goals, objectives, and general plan were presented to OHT for approval. With OHT on board, the next step was getting all of the stakeholders together for a site meeting to decide on the specifics of the plan. Present at the site meeting was a representative from CVC, the funding body for the project and the organization with authority over the floodplains in the watershed, a representative from OHT, a forestry expert, and Trainee A representing a stewardship organization. The stakeholders collectively decided on the specifics of the plan including which native species to plant and how many of each, “we decided we’ll have so many nannyberries, so many oak trees, and so many buttonbushes and stuff like that. That was our plan, the detailed plan” (Trainee A).

5.2.1.4 Implementation

Prior to starting any planting, the plan was approved by the stewardship organization represented by Trainee A as well as OHT. Obtaining approval from OHT was a lengthy process, “We worked for quite a few years to get Ontario Heritage Trust to allow us to do this and last year we finally got the approval and after signing a 30 page thick agreement to enter document they let us go in” (Trainee A). Site visits were undertaken to confirm the suitability of the site for digging holes without the aid of machinery. In fall 2015 two school buses of high school students came to Scotsdale Farm, had the project explained to them, and were shown how to properly space and plant the trees and shrubs and secure coconut fibre mulch mats around their bases. The physical implementation of the plan was completed in one day.

5.2.1.5 Monitoring and Evaluation

Monitoring of the site had not yet begun at the time of the interview as the planting was only completed in fall 2015. Trainee A will monitor the site on an annual basis for an unspecified number of years. The site will be monitored to see “what the mortality rate of the trees is, how well they’re doing and whether we can put in some more” (Trainee A). In terms of monitoring the dragonfly population, Trainee A stated that the entomologist would “stop by and take a look because it was his idea and I wanted to let him know that it took awhile but we finally came through”. No plans currently exist to share the monitoring data beyond informally letting CVC and OHT know how things are progressing. Based on the goals and objectives of the project, the success of the project will be determined by whether or not water retention capacity was enhanced and dragonfly habitat was improved. Given the length of time required to allow for the planted trees and shrubs to grow and mature, evaluating the success of the project will not be possible for several years.

5.2.1.6 Ecological Outcomes

Woody Vegetation Inventories

Two 42 m x 22 m quadrats were inventoried for woody vegetation, one in the restoration area and one in the reference area. Table 5.1 provides a summary of the species found in each quadrat, the abundance of each species, and the total number of individuals across all species. The total number of species (richness) found in the reference area quadrat was 13 and 11 in the restoration area quadrat. The reference area quadrat had a total of 198 individuals compared to 170 found in the restoration area quadrat (150 planted in fall 2015, 20 present prior to the planting). All of the species inventoried across both areas are native to the region with the exception of the common apple (*Malus pumila*) found in the restoration quadrat which is a naturalized species originally from Europe and western Asia (Barnes & Wagner, 2011).

Table 5.1. RI1 woody vegetation inventories summary

Restoration Area			Reference Area		
Species	Individuals	Stems	Species	Individuals	Stems
Populus balsamifera	33	38	*Acer saccharum*	67	67
Cornus stolonifera	20	59	*Tsuga canadensis*	27	27
Viburnum lentago	20	34	*Fraxinus americana*	20	21
Sambucus canadensis	20	29	*Sambucus canadensis*	18	29
Cephalanthus occidentalis	19	24	*Cornus alternifolia*	14	22
Thuja occidentalis	16	16	*Thuja occidentalis*	12	12
Acer saccharum	15	15	*Acer spicatum*	11	14
Quercus rubra	15	15	*Ribes triste*	8	8
Betula papyrifera	10	10	*Betula alleghaniensis*	7	8
Juglans nigra	1	1	*Fagus grandifolia*	6	6
Malus pumila	1	1	*Tilia americana*	4	5
			Ulmus americana	3	3
			Acer saccharinum	1	1
Total	170	242	Total	198	223

Shannon Entropy (H)

As shown in Table 5.2, the Shannon entropy values for the restoration area and reference area quadrats are 2.196 and 2.128 respectively. The restoration area has the same diversity as a community with 9 equally-common species while the reference area has the same diversity as a community with 8 equally-common species. Therefore, when both richness and abundance are accounted for, the diversity of the restoration area is higher than the diversity of the reference area.

Table 5.2. Measures of diversity for RI1 restoration and reference areas

	Richness (S)	Shannon entropy (*H*)	Effective number of species
Restoration area	11	2.196	8.989
Reference area	13	2.128	8.398

Vegetation Structure

Three variables were considered concerning vegetation structure of the restoration area quadrat – growth rate, average life span, and height. The number of species identified in the restoration area woody vegetation inventory falling within each of the categories of the different classification systems for the three variables is summarized in Table 5.3 (see Appendix L for a detailed breakdown by species). The species identified in the woody vegetation inventory represent a mix of growth rates, life spans, and heights. Only small shrubs are not represented in the restoration area, all other categories within the various classification systems are represented by at least one of the species found within the restoration area quadrat.

Table 5.3 Summary of RI1 inventoried species' growth rates, average life spans, and heights

		Height	
Growth rate	Average life span	Trees	Shrubs
Slow-growing: 3	Short-lived: 5	Small: 3	Small: 0
Moderately slow-growing: 1	Moderately short-lived: 1	Medium-sized: 3	Medium: 3
Moderately fast-growing: 3	Moderately long-lived: 3	Large: 3	Large: 1
Fast-growing: 4	Long-lived: 2		

Species' Tolerances

Tolerances to drought, flooding, wind, ice storms, shade, browsing, heat, fire, gypsy moth, and Asian longhorned beetle (ALHB) were considered for all of the species identified in the woody vegetation inventories. These tolerances are presented in detail in Appendix J and summarized in Table 5.4 as the proportion of species within each area capable of tolerating the various disturbances and pests. Neither area is entirely susceptible to any of the disturbances and pests considered. In fact, in the majority of cases, more than half of the species in each area are tolerant of the disturbances and pests. When comparing the two areas, the restoration area has a greater percentage of species able to tolerate seven of the ten disturbances and pests. For example, 64% of species (7 out of 11) in the restoration area tolerate drought compared to 54% in the reference area (7 out of 13).

Table 5.4 Percentage of RI1 inventoried species capable of tolerating various disturbances and pests

	Drought	Flooding	Wind	Ice Storms	Shade	Browsing	Heat	Fire	Gypsy Moth	ALHB
Restoration area	64%	55%	73%	55%	45%	55%	45%	36%	55%	73%
Reference area	54%	54%	54%	31%	85%	62%	46%	8%	38%	62%

5.2.1.7 Social Outcomes

Although the implementation of the restoration initiative was only completed in fall 2015, several social outcomes have been observed. First, Trainee A believes some degree of learning took place during the implementation phase where high school students took part in planting the trees and shrubs. As part of their involvement, the students were informed of the purpose of the project and had the relationship between the work they were doing and the dragonfly population explained. Trainee A described this stating that they explained "the relationship between the trees and the dragonflies, which seems a little farfetched, but I think they could understand that there's a connection there. We hope that they'll retain some of that information". Second, collaboration was enhanced between OHT, CVC, and the stewardship organization, "it went 0 to 100 in a very quick time" (Trainee A). Third, and related to enhanced collaboration, is a perception that there has been a shift in the way that OHT views the potential of the land and in the willingness to experiment with restoration at the site. Trainee A asserts that "Because of the success of this project and because it didn't cost them anything and it's not hurting anything in their plans" the opportunity exists to do more work at Scotsdale Farm in the future. Finally, Trainee A believes that the initiative is responsible for greater participation in relation to caring for the watershed because OHT agreed to participate in this initiative and has shown a willingness to do so again in the future.

5.2.2 Evaluation of Restoration Initiative One

Analysis of the descriptive results regarding restoration process and social outcomes for RI1 involved following the coding procedure outlined in section 3.5.2 to code for evidence of the principles for building social-ecological resilience. Ecological outcomes were evaluated with respect to whether or not they qualitatively reflect the criteria for the principles considered key SES properties to be managed (see section 3.5.2.1 for more detail). Details of the analysis of the results are presented in Appendix M. Based on this analysis, Table 5.5 provides an overview of the evaluation of RI1 showing where evidence of principles is present and the magnitude of that evidence. With regard to restoration process and social outcomes, evidence is conveyed as absent (white boxes), present (light grey boxes), or emphasized (dark grey boxes). Similarly, Table 5.5 shows where ecological outcomes do not reflect the criteria for a principle (white boxes), where they appear to be on a trajectory towards reflecting the criteria (light grey boxes), and where they fully reflect the criteria for a principle (dark grey boxes).

The evaluation of RI1 revealed evidence of the principles for building social-ecological resilience across the phases of restoration process and outcomes. As shown in Table 5.5, the principles vary in terms of the specific phases in which they are reflected and whether they appear in ecological and social outcomes. Evidence of the principles considered key SES properties to be managed appears most frequently in the earlier phases of the restoration process. In addition, several ecological outcomes are considered expressions of the principle 'maintain diversity and redundancy'. For example, the diverse species assemblage in the restoration area, relative to the reference area, is an outcome of the planting completed in fall 2015 which fully reflects the criteria for this principle. There are no results/products representing expressions of the principles ‘manage connectivity’ and ‘manage slow variables and feedbacks’ to be evaluated. Effects associated with these principles are discussed in Chapter Six and Appendix H.

Of the four principles considered key attributes of the governance system, only evidence of ‘encourage learning and experimentation’ is found throughout the entire restoration process and social outcomes. None of the phases of restoration process contain any passages coded as magnitude 1. However, passages coded as magnitude 1 are found in social outcomes for all principles except ‘foster CAS thinking’. For example, in relation to ‘broaden participation’, Trainee A explains that collaboration between organizations with regard to caring for the watershed was definitely enhanced as a result of the restoration process, “...it went 0 to 100 in a very quick time ... the cooperation with Ontario Heritage Trust was definitely evident and satisfactory to all parties”. The enhanced collaboration resulting from the restoration process also relates to the principle ‘promote polycentric governance systems’ as the “parties” Trainee A refers to are organizations with different sources of authority that worked together on this project and are expected to work together on future projects at Scotsdale Farm, “we very likely will be doing more work” (Trainee A).

Table 5.5 Overview of the evaluation of RI1 in relation to social-ecological resilience. The degree of magnitude of the principles is conveyed through white boxes (absent), light grey boxes (present), and dark grey boxes (emphasized in at least one instance).

			GENERAL PHASES OF ECOLOGICAL RESTORATION PROCESS					RESTORATION OUTCOMES	
			Problem identification	Defining goals and objectives	Designing a restoration plan	Implementation	Monitoring and evaluation	Ecological outcomes	Social outcomes
PRINCIPLES FOR BUILDING RESILIENCE IN SES	**Key SES properties to be managed**	Maintain diversity and redundancy							NA
		Manage connectivity						NATA	NA
		Manage slow variables and feedbacks						NATA	NA
	Key attributes of the governance system	Foster CAS thinking						NA	
		Encourage learning and experimentation						NA	
		Broaden participation						NA	
		Promote polycentric governance systems						NA	

NA = not assessed, NATA = not able to assess

5.3 Restoration Initiative Two

Now in the second year of a five year plan, RI2 focuses on restoring in-stream habitat in order to address declining brook trout populations identified through long-term watershed monitoring. Concern over declines in this population in the Credit River Watershed prompted collaborative action from CVC, a local stewardship organization, and several conservation-minded angling groups. Led by CVC, a plan was created to guide restoration and monitoring activities within the Upper Credit Conservation Area (UCCA) over five years starting in 2015. The plan is intended to remediate the issues caused by historic agricultural activities (e.g., cattle pasturing) and builds on previous work done in UCCA. Over the course of five years the following restoration work is planned: installation of silt traps to narrow and deepen the channel; installation of habitat structures and boulders to increase fish and benthic macroinvertebrate habitat; addition of gravel in sections of the stream to increase the availability of spawning substrate suitable for brook trout; and planting native vegetation in the riparian zone to shade the channel and reduce water temperatures. Furthermore, yearly monitoring includes electrofishing, collection of temperature data, benthic macroinvertebrate sampling, spawning surveys, substrate surveys, and monitoring plant survivorship. Implementation of the plan is being led by the local chapter of a conservation organization with support from the other project partners and interested volunteers.

5.3.1 Results of Restoration Initiative Two

5.3.1.1 Problem Identification

CVC conducts ongoing, watershed-wide monitoring. While doing a 10-year review of their integrated watershed monitoring program, it was determined that brook trout population numbers were declining throughout the watershed. The monitoring data showed that the population in UCCA mirrored the declining trend observed in the watershed as a whole, “This project is on the Credit River which contains one of the populations and their monitoring also showed that the population in this area is declining” (Trainee B). In addition, water quality monitoring in this particular area suggested that temperatures were increasing through this reach. Finally, it was apparent through visual observations that the channel in this location was over-widened in comparison to a downstream reference reach. The combination of these three factors identified through long-term, watershed-wide monitoring highlighted the need for restoration along this reach within UCCA.

5.3.1.2 Defining Goals and Objectives

The goal of this five year initiative is to restore brook trout habitat in UCCA and by extension, increase brook trout population numbers in the reach of concern. CVC, project lead at the time, specified three interconnected objectives to support the achievement of this goal. The first objective is to narrow and deepen the channel to reference conditions that are downstream of the site. The second objective is to reduce stream temperatures. The third objective is to increase habitat features for fish and benthic macroinvertebrates.

A set of metrics related to the objectives will be considered during monitoring to assess progress made towards achieving the objectives. Although not a formal goal, collaboration and volunteer engagement are also important components of the project. The initiative is intended to foster relationships between different organizations, engage citizens, and increase the volunteer pool for stewardship activities, “it’s more a part of the project than a goal of the project, if you know what I mean. It’s how the project is being run, it’s what we want more so than a goal. We’re not trying to achieve it at the end, we’re trying to achieve it all the way through” (Trainee B).

5.3.1.3 Designing a Restoration Plan

Designing the restoration plan was led by CVC, “they developed this formal five year plan in concert with the other groups” (Trainee B). The restoration work planned for the project as a whole is listed in the overview of section 5.3. The specific techniques employed in year one of the project (2015) included the installation of habitat structures and silt traps as well as riparian planting. Several habitat structures were included in the plan based on the location selected for their placement within the channel (e.g., outside of a meander, along a run). The structures installed in year one of the plan were wood and rock habitat structures, an embedded woody habitat structure, and a single angle log habitat structure. The riparian planting was done using native trees and shrubs in an area where silt traps had previously been installed by CVC and were showing signs of successfully narrowing the channel. The new silt traps were intended to build on this work. In addition to outlining the techniques chosen to achieve the project goal and objectives, the plan has details on community engagement and volunteerism built in. Each work day event over the five years is planned out with the knowledge that it will be carried out by project partners and volunteers from the community and beyond, “It’s not an after product like, okay how do we get this done? Maybe we can use volunteers. I think the idea has always been use volunteers” (Trainee B).

5.3.1.4 Implementation

Implementation of year one of the five year plan took place over the spring, summer, and fall of 2015 and was led by the local chapter of a conservation organization with funding acquired by CVC. Information about the project and opportunities to get involved were promoted on CVC’s events and volunteer web pages as well as through social media including Facebook and Twitter. Several work days were carried out by youth in a summer program run by CVC while the remainder were well attended by volunteers from across the watershed and beyond. Planting days, habitat structure days, and silt trap construction days combined with benthic sampling, electrofishing, and spawning surveys resulted in a total of 14 work days in UCCA in year one. Each work day started with a description of the project, the work being done that day, and a safety talk. Because work days were so well attended, care had to be taken to minimize potential negative environmental impacts such as excessive trampling of vegetation and the creation of multiple trails and paths along the channel. Keeping tools and equipment in a central location and having only one path from that location to the work sites helped minimize the impact. Moreover, because spawning surveys are conducted at a sensitive time, volunteer numbers were limited for this event and a specific protocol was followed to limit habitat disturbance, “So in other words, if you don’t have to walk straight up the river, walk on the banks so you’re not disturbing habitat. Sometimes though if you want to actually do a proper survey, sometimes you have to get in the water so you can actually see what you’re looking at” (Trainee B). Moving forward, a number of applications have been submitted for funding for the implementation of the next four years of the plan.

5.3.1.5 Monitoring and Evaluation

Monitoring is built into every year of the plan with year one monitoring serving as the baseline. Monitoring activities undertaken in 2015 included electrofishing, benthic sampling, temperature data collection, and brook trout spawning surveys. These activities, plus plant survivorship monitoring and pebble counts, will be undertaken in each of the remaining years of the project. With the exception of temperature data collection which is done using data loggers, anyone is welcome to volunteer to help out with monitoring activities. To the extent possible, the data collected through monitoring will inform the work to be completed in the following years of the project. For example, “If we go back next year and look at the plantings that we did this year and let’s say a group of plantings didn’t work but everything else did. I for sure would look at that and say why is that?” (Trainee B).

Monitoring data will also be used to evaluate the success of the project. Over the years, the data will be compared to the baseline to determine changes in a set of metrics, “specific things we’re going to be monitoring to assess how we’re moving in that direction” (Trainee B). Certain changes in these metrics represent progress made towards achieving the objectives of the project. As an example, “For temperature, if it’s not increasing temperature through the restoration reach like it currently is, that’s a success” (Trainee B). Success will also be determined by the ability to maintain an active volunteer base to implement all five years of the plan, “a five year project being implemented the vast majority by volunteers... if we actually achieve all the plantings and all the structures and all the things, I would consider that a huge success in terms of the social aspect” (Trainee B). In terms of sharing information, there is no formal plan in place to share monitoring data prior to the completion of the final year of the project, at which time outcomes will be shared with the public. However, the data will be made available to anyone who requests it. In addition, if the project shows signs of success as it matures, that information will be shared widely, “if it starts showing success, I’m pretty sure we’ll be telling everyone.” (Trainee B). Similarly, even if the project does not show signs of success, that information will also be made available, “If we don’t show success though, I’m more of a science guy so that’s a result too, to me. So I’m not trying to say that, “if it works, then we’re going to tell everyone, if it doesn’t we’re going to be quiet”. That’s not what I’m saying” (Trainee B).

5.3.1.6 Ecological Outcomes

Woody Vegetation Inventories

Two 50 m x 10 m quadrats were inventoried for woody vegetation, one on each bank of the restoration reach and one on each bank of the reference reach. Table 5.6 gives a summary of the species found in each reach (right bank and left bank inventories have been combined), the abundance of each species, and the total number of individuals across all species. A total of 22 different species (richness) were found in both the restoration and reference reach inventories. The reference reach quadrats had a total of 411 individuals compared to 528 found in the restoration reach quadrats (177 planted in fall 2015).

Several species inventoried in both reaches are not native to the region including multiflora rose (*Rosa multiflora*), tartarian honeysuckle (*Lonicera tatarica*), Norway spruce (*Picea abies*), and Manitoba maple (*Acer negundo*) which has been naturalized beyond its natural range in Canada (Farrar, 2010). In addition, several plants were identified only to the genus *Salix* or *Crataegus* and not to species. Willows (*Salix spp.*) are notoriously difficult to identify to species for several reasons including their "morphological characteristics, genetic variation among individuals, the variation they exhibit in response to their physical environment, and the apparent frequency with which they hybridize" (Barnes & Wagner, 2011, p. 135). As such, positive identification of willows often requires that the plant be observed during both flowering and fruiting (Farrar, 2010). Similarly, Hawthorns (*Crataegus spp.*) often hybridize and have been classified and reclassified numerous times (Kershaw, 2001). According to Kershaw (2001, p. 141), Hawthorns "without flowers or fruits often cannot be identified to species, even by experts".

Table 5.6 RI2 woody vegetation inventories summary

Restoration Area			Reference Area		
Species	Individuals	Stems	Species	Individuals	Stems
Thuja occidentalis	149	172	*Prunus virginiana*	237	320
Salix spp.	83	141	*Thuja occidentalis*	107	137
Cornus stolonifera	61	145	*Acer saccharinum*	11	11
Viburnum lentago	57	84	*Salix spp.*	8	13
Sambucus canadensis	36	53	*Viburnum trilobum*	6	10
Prunus virginiana	32	38	*Viburnum lentago*	6	6
Acer saccharinum	18	18	*Fraxinus nigra*	5	8
Picea glauca	17	17	*Lonicera tatarica*	4	18
Cornus amomum	16	31	*Rosa multiflora*	4	10
Ulmus americana	15	17	*Picea glauca*	4	5
Populus tremuloides	15	15	*Prunus serotina*	4	4
Betula papyrifera	9	9	*Ulmus americana*	2	5
Ribes americanum	6	6	*Acer negundo*	2	4
Rosa multiflora	4	4	*Pinus strobus*	2	2
Viburnum trilobum	2	15	*Rubus occidentalis*	2	2
Larix laricina	2	2	*Cornus stolonifera*	1	8
Lonicera tatarica	1	1	*Tilia americana*	1	7
Crataegus spp.	1	3	*Cornus alternifolia*	1	3
Picea abies	1	1	*Ribes americanum*	1	1
Ulmus rubra	1	1	*Tsuga canadensis*	1	1
Populus grandidentata	1	1	*Crataegus spp.*	1	1
Amelanchier arborea	1	1	*Cornus amomum*	1	1
Total	528	775	Total	411	577

Shannon Entropy (H)

Shannon entropy values (*H*) for the restoration reach and reference reach quadrats are shown in Table 5.7. The restoration reach has a Shannon entropy of 2.295 or the same diversity as a community with 10 equally-common species while the reference reach has a Shannon entropy of 1.405 or the same diversity as a community with 4 equally-common species.

Table 5.7 Measures of diversity for RI2 restoration and reference reaches

	Richness (S)	Shannon entropy (*H*)	Effective number of species
Restoration area	22	2.295	9.928
Reference area	22	1.405	4.075

Vegetation Structure

The growth rates, average life spans, and heights of the 22 species identified in the restoration reach woody vegetation inventory are summarized in Table 5.8 (see Appendix N for a detailed breakdown by species). A variety of growth rates, life spans, and heights are represented by the species identified in the inventory. Fast growing species were most common while short-lived species represent the greatest number of species in terms of longevity. Life span for the Willows (*Salix spp.*) and Hawthorns (*Crataegus spp.*) was not included as longevity depends on the particular species being considered and these plants were identified to genus only. For trees, medium-sized trees were most common followed by small and then large trees. Large shrubs were most frequently inventoried followed by medium shrubs and one small shrub.

Table 5.8 Summary of RI2 inventoried species' growth rates, average life spans, and heights

		Height	
Growth rate	Average life span	Trees	Shrubs
Slow-growing: 5	Short-lived: 12	Small: 5	Small: 1
Moderately slow-growing: 3	Moderately short-lived: 1	Medium-sized: 6	Medium: 4
Moderately fast-growing: 6	Moderately long-lived: 5	Large: 4	Large: 7
Fast-growing: 8	Long-lived: 2		

Species' Tolerances
Tolerances to ten disturbances and pests were considered for all of the species identified in the woody vegetation inventories. These tolerances are summarized in Table 5.9 in terms of the percentage of species resistant to, or able to tolerate, the different disturbances and pests (see Appendix K for greater detail). In all but one instance, at least half of the species in either reach are capable of tolerating the selected disturbances and pests. For six of the ten disturbances and pests considered, the reference reach has a greater percentage of tolerant species than the restoration reach.

Table 5.9 Percentage of RI2 inventoried species capable of tolerating various disturbances and pests

	Drought	Flooding	Wind	Ice Storms	Shade	Browsing	Heat	Fire	Gypsy Moth	ALHB
Restoration reach	68%	59%	77%	55%	64%	64%	64%	32%	64%	73%
Reference reach	73%	64%	68%	55%	73%	59%	50%	45%	68%	82%

In-stream Habitat Diversity
Over seven hours of underwater video footage was recorded between the four habitat structures installed in the restoration reach at UCCA in 2015. The video footage captured a total of 46 fish appearances and one crayfish (Cambaridae family) (Ontario Nature, 2008) at site 1. On more than one occasion, two or more fish were captured in the frame at the same time. Table 5.10 details the site numbers as listed in the restoration plan, the types of habitat structures, their locations, the total amount of video footage recorded at each structure, and the number of times one or more fish was observed at the structure.

Positive identification of fish species was made difficult by a number of factors including turbidity, lighting, and the speed at which fish passed through the frame. Instead, where possible, fish were identified as belonging to the families Cyprinidae (carps and minnows) and Centrarchidae (sunfishes and basses) (Holm et al., 2010). These findings correspond fairly well with the results from electrofishing performed at the UCCA restoration reach station in 2010 which indicate that all species sampled belonged to the families Cyprinidae, Centrarchidae, and Catostomidae (suckers) (McIsaac et al., 2015).

Table 5.10 Summary of fish observations at UCCA habitat structures

Site #	Structure	Location	Video Time	Fish Presence
1	Embedded woody habitat	Pool	88 minutes	20 appearances
17	Wood and rock habitat structure	Pool	63 minutes	15 appearances
22	Wood and rock habitat structure	Run	153 minutes	10 appearances
31	Single angle log	Run	126 minutes	1 appearance

Temperature
As shown in Table 5.11 over the same 12-hour period on the same day in June, the maximum stream and air temperatures were experienced in 2014 while the highest range and average hourly rate of change were recorded in 2015, the year with the lowest maximum air and stream temperatures. The lowest stream temperature range and average hourly rate of change were experienced in 2016.

Table 5.11 Comparison of stream temperature and maximum air temperature at the same UCCA location in 2014, 2015, and 2016

	Stream Temperature (°C)				Maximum Air Temperature (°C)
	Maximum	Minimum	Range	Average Hourly Rate of Change	
2014	22.1	18.2	3.9	+0.3	25.9
2015	20.3	14.7	5.6	+0.4	20.5
2016	21.7	17.9	3.8	+0.2	22.4

5.3.1.7 Social Outcomes

With only the first year of implementation complete (see section 1.3 for discussion around limitations), some social outcomes are already evident. One such example is the learning that takes place at each work day, "I would say that every day a new volunteer comes out, they're learning something because we always make a point of explaining what we're doing and why" (Trainee B). Another social outcome that can be discussed at this early stage is the enhanced collaboration between organizations as a result of the initiative. Though some of the project partners have a long history of working together, this is the first time all of the partners have worked together on a single project, "I don't know of [a project] where all of these groups have been working together. So I would like to suggest that it might be enhanced in that regard, that there's more groups working all on one project together" (Trainee B). Finally, it is worth mentioning that although there is no baseline for comparison, participation in the initiative through volunteerism has been exceptional in the first year. Trainee B explained, "...it's been really great. I mean, because it's year one it's hard to gauge, is that increasing. If it increases I think we're going to have too many volunteers. So I would suggest it might be hard to increase from this but it's been really good".

5.3.2 Evaluation of Restoration Initiative Two

The descriptive results for RI2 were analyzed in the same manner as was done for RI1. The details of the analysis of the results are presented in Appendix O and the evaluative findings from the analysis are summarized in Table 5.12 using the same system of shading described for RI1 to demonstrate varying degrees of magnitude of the evidence.

Evidence of principles considered key SES properties to be managed is found in almost every phase of the restoration process including evidence coded as magnitude 1 for the defining goals and objectives phase. As an example, when describing goals and objectives of the restoration initiative, Trainee B explained that a “big component” of the project relates to bringing together different organizations, volunteers, and citizens and fostering relationships between those diverse groups. With respect to ‘maintain diversity and redundancy’, evidence is also found of ecological outcomes. No results/products representing expressions of the principles ‘manage connectivity’ and ‘manage slow variables and feedbacks’ could be evaluated. Effects associated with these principles are discussed in Chapter Six and Appendix H.

While evidence of the principles considered key attributes of the governance system is collectively found throughout the phases of restoration process and social outcomes, only evidence of ‘broaden participation’ is present for all phases and for social outcomes. Moreover, evidence coded as magnitude 1 relates only to ‘broaden participation’. For example, when describing social outcomes and the involvement of relevant stakeholders in the initiative, Trainee B emphasized, “the amount of participation has been surprising, like really excellent and surprising”.

Table 5.12 Overview of the evaluation of RI2 in relation to social-ecological resilience. The degree of magnitude of the principles is conveyed through white boxes (absent), light grey boxes (present), and dark grey boxes (emphasized in at least one instance).

			GENERAL PHASES OF ECOLOGICAL RESTORATION PROCESS					RESTORATION OUTCOMES	
			Problem identification	Defining goals and objectives	Designing a restoration plan	Implementation	Monitoring and evaluation	Ecological outcomes	Social outcomes
PRINCIPLES FOR BUILDING RESILIENCE IN SES	Key SES properties to be managed	Maintain diversity and redundancy							NA
		Manage connectivity						NATA	NA
		Manage slow variables and feedbacks						NATA	NA
	Key attributes of the governance system	Foster CAS thinking						NA	
		Encourage learning and experimentation						NA	
		Broaden participation						NA	
		Promote polycentric governance systems						NA	

NA = not assessed, NATA = not able to assess

5.4 Restoration Initiative Three

RI3 is an ongoing program of restoration focused on restoring clean, clear, cold water in the Mill Creek Watershed (a subwatershed of the Southern Grand River Watershed) following the 2005 removal of a small dam erected in the 1950s. The removal of the dam and the discovery of a spring-fed creek in the watershed brought attention to the potential of the system to support a brook trout population again. Led by the local chapter of a conservation organization, and with the support and involvement of many other conservation and stewardship organizations, landowners, and community members, a number of projects all working towards the goal of restoring a healthy system capable of supporting brook trout have been completed throughout the watershed. Examples of the work done includes, putting up fencing to stop cattle from entering the stream, installing beaver bafflers, creating rocky ramps and vortex weirs, and most recently, the wild transfer of brook trout from a neighbouring watershed. Aided by PIT tags implanted in the transferred fish, monitoring will provide information on the survival and preferences of the fish. RI3 has evolved over several years as new issues come to light and as the system responds to the work done in previous years. Presently, a plan is being created to guide the next five years of the project.

5.4.1 Results of Restoration Initiative Three

5.4.1.1 Problem Identification

Spurring the initiation of RI3 was a combination of the identification of a problem and the identification of an opportunity. The problem was a small dam impeding the natural flow regime of Mill Creek and creating a shallow lake behind the dam. The dam contributed to warmer stream temperatures, reduced and degraded in-stream habitat, and ultimately the extirpation of brook trout from the system. On the other hand, an opportunity was identified by the president of the local chapter of a conservation organization when he discovered cold water springs in the watershed. This discovery drew attention to the fact that the system was once a cold water system capable of supporting cold water species such as brook trout. With the removal of the dam in 2004-2005, the stream was free to find a more natural path but the watershed as a whole required work to help the system recover and repair the damage caused by the dam over several decades. Issues of excessive fine sediment, stream widening, poor water quality associated with cattle having access to the stream, and flooding of woodlots caused by beaver dams have been identified over the years since the long-term initiative to restore the system to a functional cold water system began. These issues were brought forward by landowners, members of the stewardship organization Habitat Haldimand, and local chapter members and were discussed with other conservation organizations as well as experts from the Grand River Conservation Authority (GRCA), TUC, and MNRF.

5.4.1.2 Defining Goals and Objectives

The goals and objectives of the initiative were established by the chapter president with input from experts at TUC, GRCA, and MNRF. The overarching goal is to restore clean, clear, cold water to support a self-sustaining brook trout population. In line with the goal of the initiative, the objectives are to reduce peak stream temperatures, remove barriers to fish passage, enhance habitat, narrow and deepen the channel to flush excess sediment, and educate the local community about the importance of the coldwater resources in their watershed. The latter is important for gaining support for the initiative and creating something the community can be proud of, "you're not going to be successful unless you get the local landowners to buy in and understand the value of what's happening and how it's beneficial to them and beneficial to everyone in general" (Trainee C).

5.4.1.3 Designing a Restoration Plan

Similar to the goals and objectives, the plan for RI3 was designed by the chapter president with input and advice from staff at TUC, GRCA, and MNRF as well as the president of a neighbouring chapter. The process for developing the plan involved considering the identified problems and linking solutions and specific techniques to those problems. A report completed by students at Niagara College looking at the potential for restoration at the site of the former dam was drawn on for technical information. As new problems and opportunities have been identified over the years, the plan has adapted accordingly. For example, beavers were not a problem when the plan was initially designed. However, shortly after beavers became a major issue as landowners were losing acres of valuable hardwoods as a result of dams on their properties.

The specific techniques that have been included in the plan include: riparian planting to shade the channel; installing sweepers and deflectors to flush excess sediment; pollarding to increase the insect population in a nursery stream; removing beaver dams and installing beaver bafflers to eliminate flooding; creating rocky ramps and vortex weirs to aerate the water; adding spawning gravel for additional habitat; fencing cattle out of the stream; creating a bed level crossing for cattle; and the wild transfer of adult brook trout. A comprehensive plan was completed in April 2016 that will guide the chapter's restoration activities for the next five years. The individual who developed the plan was hired by, and worked with, the local chapter and TUC staff.

5.4.1.4 Implementation

Implementation of the restoration plan has involved a number of different aspects. First, in terms of sharing information about the initiative, three open houses were held early on in the project to share the goals, objectives, and general restoration plan in an effort to inform and engage the community. Since then, updates about the initiative and progress made have been shared with approval agencies, past and present volunteers through work day reports, with the community informally through conversation, and more broadly through TUC and GRCA newsletters. Second, funding and resources for the project have been secured from a number of sources including the Izaak Walton Fly Fishing Club, TD Friends of the Environment Fund, Trillium Fund, Haldimand Stewardship Foundation, and Union Gas Centennial Fund. Several landowners have also contributed to the initiative by donating, storing, or moving materials for projects, "the landowners have done many different things by helping move materials in or clearing pathways for us to get in more easily and things like that" (Trainee C). Moreover, support from volunteers and landowners has been essential to the physical implementation of the plan, as has guidance and advice provided by professionals present at specific work days, "definitely they had an input and so on to make sure that things were going properly" (Trainee C). Third, approvals were obtained from the appropriate agencies for certain projects and permission granted by landowners to access and do work on their land. Fourth, an adaptive approach to implementation has been taken where work days have been prioritized and reprioritized as new issues have come to light and previously completed work that is not performing as intended is adjusted or altered to achieve the desired outcome.

5.4.1.5 Monitoring and Evaluation

Monitoring has been ongoing throughout the restoration initiative. The information collected has informed and influenced the restoration plan by providing an understanding of the degree to which the work that has been completed has had, or is having, the intended results and by identifying where to focus future work, "it's more that type of monitoring – we're doing this project to do this and then observing whether this actually happens" (Trainee C). Monitoring activities have, to a large extent, been a collaborative effort with staff at the TUC Ontario office providing resources and expert advice. The support provided by TUC includes supplying data loggers for temperature monitoring and downloading the data, providing a reader and portable PIT tag antenna to monitor the presence and location of PIT tagged brook trout and downloading the data, and, in the past, conducting water quality monitoring, benthic sampling, and electrofishing. Observational and incidental monitoring has also been done by chapter members, members of Habitat Haldimand, and landowners "all sort of meeting and talking on a casual basis more than a big meeting or anything like that about what's happening, what's changing, what's not changing" (Trainee C). Monitoring data has been, and will continue to be, shared with TUC, with the approval agencies (i.e., MNRF, GRCA), informally with those involved in the project through work day reports, and with community members through informal conversations.

To evaluate the success of the restoration initiative, the local chapter leading the initiative will refer back to the goals and objectives of the project and determine whether the techniques used were successful in achieving the project objectives and whether that results in achievement of the overall goal. So far monitoring data has suggested that progress is being made towards achieving project objectives but further restoration and monitoring activities are planned for the coming years.

5.4.1.6 Ecological Outcomes

Fish Species Diversity and Response Diversity
Prior to the October 2015 transfer of 16 wild brook trout from a neighbouring watershed into Emerson Creek, no coldwater species were recorded through monitoring efforts in the Mill Creek watershed. Examples of warmwater species identified through electrofishing efforts in 2010, 2011, and 2014 include green sunfish (*Lepomis cyanellus*),

stonecat (*Noturus flavus*), and common carp (*Cyprinus carpio*). Coolwater species identified include common shiner (*Luxilus cornutus*), white sucker (*Catostomus commersonii*), central mudminnow (*Umbra limi*), Johnny darter (*Etheostoma nigrum*), rock bass (*Ambloplites rupestris*), creek chub (*Semotilus atromaculatus*), blacknose dace (*Rhinichthys atratulus*), and northern pike (*Esox lucius*).

Following the wild transfer, three brook trout redds were observed during spawning surveys conducted in December 2015. In January 2016, 14 of the 16 PIT tagged brook trout were found in Emerson Creek through portable PIT tag antenna surveys.

In-stream Habitat Diversity
The spawning habitat created with the addition of gravel in Emerson Creek, a spring-fed tributary of Mill Creek, showed evidence of being utilized by brook trout in 2015. Specifically, spawning surveys conducted in December 2015 resulted in the observation of three redds. In addition, the fact that 14 of the 16 PIT tagged brook trout were found in Emerson Creek, the same tributary they were released into in October 2015, during portable PIT tag antenna surveys in 2016 suggests that the habitat available for feeding is suitable.

Barriers to Flow
As stated in the Mill Creek watershed five year plan, the beaver bafflers, installed in July 2010 in a previously dammed location within the watershed, continue to adequately control beaver activity and in doing so, serve their purpose of maintaining unimpeded flow through the reach.

5.4.1.7 Social Outcomes

Since the initiative began, a number of social outcomes have been observed. Participation in relation to caring for the watershed has grown from a group of dedicated volunteers to a whole community of interested and engaged individuals, “I think that just the whole project has caused a greater participation of community people” (Trainee C). Related to greater participation is the fact that learning has taken place which has resulted in a greater awareness of what can be achieved in the watershed:

> ...because of the work that’s being done and the engagement, I would think that the local landowners and other people who have come and taken part and worked on one or more work projects, they’ve definitely become more aware of what can be done as far as improving watersheds, habitat, and so on. (Trainee C)

The nature of the work involved in this initiative necessitates a collaborative effort between a number of different groups, “it involves so many different people because once you start dealing with water, then you have all of the different governments and so on and agencies” (Trainee C). As such, collaboration with regard to caring for Mill Creek Watershed has been enhanced through this initiative, “You have local Haldimand governments, you have GRCA, you have the Ministry, you have organizations like Trout

Unlimited Canada, you have Habitat Haldimand locally and so on so there's a huge amount of collaboration and cooperation to make it all work." (Trainee C). Finally, there is a willingness to experiment with techniques that have never been used in the watershed before and to modify those techniques to suit the conditions of the watershed, "So like beaver bafflers ... that was I think a new technique and we learned from that how it didn't really work the first time we put it in or didn't work as effectively as it might have and what we had to do to change it" (Trainee C).

5.4.2 Evaluation of Restoration Initiative Three

The evaluation of RI3 was undertaken following the same procedure outlined for RI1 and RI2. Appendix P provides details of the analysis of the descriptive results while Table 5.13 presents a summary of the evaluative findings including where evidence is found across the phases of restoration process and outcomes, as well as, the magnitude of that evidence.

As shown in Table 5.13, the evaluation of RI3 revealed evidence of the principles considered key SES properties to be managed across the phases and ecological outcomes. Whereas evidence of the first two principles is found in all phases and ecological outcomes, evidence of the principle 'manage slow variables and feedbacks' was only found in relation to monitoring and evaluation. Evidence regarding phases of restoration process was coded as magnitude 1 most frequently for the principle 'manage connectivity'. Furthermore, the elimination of barriers to flow represents an ecological outcome reflecting the criteria for this principle.

For the principles considered key attributes of the governance system, evidence was found in all phases of restoration process with the exception of the problem identification phase for the principle 'encourage learning and experimentation', and the defining goals and objectives and designing a restoration plan phases for the principle 'promote polycentric governance systems'. The implementation and monitoring and evaluation phases each have evidence coded as magnitude 1 for all of these principles except 'foster CAS thinking'. As an example, Trainee C stressed that the monitoring efforts so far have involved varying degrees of participation from several different organizations and individuals with an interest in the restoration initiative and/or the ability to provide expertise. In terms of social outcomes, evidence was found for three of the four principles with evidence coded as magnitude 1 for the principle 'encourage learning and experimentation'.

Table 5.13 Overview of the evaluation of RI3 in relation to social-ecological resilience. The degree of magnitude of the principles is conveyed through white boxes (absent), light grey boxes (present), and dark grey boxes (emphasized in at least one instance).

			GENERAL PHASES OF ECOLOGICAL RESTORATION PROCESS					RESTORATION OUTCOMES	
			Problem identification	Defining goals and objectives	Designing a restoration plan	Implementation	Monitoring and evaluation	Ecological outcomes	Social outcomes
PRINCIPLES FOR BUILDING RESILIENCE IN SES	Key SES properties to be managed	Maintain diversity and redundancy							NA
		Manage connectivity							NA
		Manage slow variables and feedbacks						NATA	NA
	Key attributes of the governance system	Foster CAS thinking						NA	
		Encourage learning and experimentation						NA	
		Broaden participation						NA	
		Promote polycentric governance systems						NA	

NA = not assessed, NATA = not able to assess

5.5 Cross-case Analysis

With each of the individual restoration initiative evaluations completed, cross-case analysis was undertaken (see section 3.5.2.4.). Information in Tables 5.5, 5.12, and 5.13 is brought together using a data matrix (Table 5.14). Table 5.14 uses the same system of shading to depict the presence and magnitude of evidence. Findings from the cross-case analysis are presented in this section and concentrate on patterns in the results among restoration initiatives. Presenting the results collectively (Table 5.14) visually illustrates the presence or absence of patterns.

Overall, Table 5.14 clearly illustrates that evidence of the principles for building resilience in SES was found across the phases of restoration process and social and ecological outcomes. Although each principle is understood to be relevant to all five phases of the restoration process, because of the large variation in size and complexity of restoration initiatives, differences in the presence and magnitude of evidence between restoration initiatives were anticipated and reinforce the importance of context.

Table 5.14 reveals a pattern in the results for the principle ‘maintain diversity and redundancy’. Evidence for this principle is particularly strong with regard to ecological outcomes. In all three cases this evidence is, in part, related to diversity in the species present and response diversity. For RI1 and RI2, the woody vegetation inventories revealed that the restoration areas are diverse relative to the reference areas and that the species found in the restoration areas are capable of exhibiting response diversity. For RI3, greater species diversity and response diversity concerns the reintroduction and survival of native brook trout to the system through wild transfer.

Conversely, patterns also emerged in terms of areas where evidence was not found. Common among all three restoration initiatives is a lack of evidence for the principle ‘promote polycentric governance systems’ in the defining goals and objectives phase, for the principle ‘manage slow variables and feedbacks’ in the implementation phase, and finally, there is no evidence of ‘foster CAS thinking’ in social outcomes.

A comparison of Table 4.3 and Table 5.14 shows that the presence and magnitude of evidence is not mirrored perfectly between the training program and the restoration initiatives. More white boxes indicating an absence of evidence are found in Table 5.14 and there are far fewer dark grey boxes indicating that a principle was emphasized. Comparing the tables also demonstrates that no evidence was found in either the assessment of the training program or evaluation of restoration initiatives in the implementation phase in relation to the principle ‘manage slow variables and feedbacks’.

Table 5.14 Overview of the evaluation of RI1, RI2, and RI3 in relation to social-ecological resilience. The degree of magnitude of the principles is conveyed through white boxes (absent), light grey boxes (present), and dark grey boxes (emphasized in at least one instance).

			GENERAL PHASES OF ECOLOGICAL RESTORATION PROCESS															RESTORATION OUTCOMES					
			Problem identification			Defining goals and objectives			Designing a restoration plan			Implementation			Monitoring and evaluation			Ecological outcomes			Social outcomes		
			1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
PRINCIPLES FOR BUILDING RESILIENCE IN SES	Key SES properties to be managed	Maintain diversity and redundancy																			NA	NA	NA
		Manage connectivity																NA TA	NA TA		NA	NA	NA
		Manage slow variables and feedbacks																NA TA	NA TA	NA TA	NA	NA	NA
	Key attributes of the governance system	Foster CAS thinking																NA	NA	NA			
		Encourage learning and experimentation																NA	NA	NA			
		Broaden participation																NA	NA	NA			
		Promote polycentric governance systems																NA	NA	NA			

NA = not assessed, NATA = not able to assess

5.6 Discussion of Key Findings

Restoration initiatives informed by the Stream Rehabilitation, From Form to Function Training Program were evaluated in terms of process and outcomes. This section discusses the key findings from the evaluation of the restoration initiatives in relation to the ecological restoration and social-ecological resilience literature.

Objective One of this research involved conceptually exploring the possibility of social-ecological resilience informing aquatic ecosystem restoration and its evaluation. The conceptual framework presented in Chapter Two illustrates the potential for Biggs et al.'s (2012) principles for building resilience in SES to inform the phases of restoration process, ultimately resulting in ecological and social outcomes on the landscape. The evaluation of restoration initiatives informed by the training program (Objective Three) provided a means of empirically testing the conceptual framework to understand whether Biggs et al.'s (2012) principles can be applied 'on the ground'. Based on the review of the ecological restoration and social-ecological resilience literature in Chapter Two, this was believed to be the first time principles for building resilience were applied specifically to an aquatic ecosystem restoration context. The results of the evaluation support and build on the key findings from the assessment of the training program by suggesting that the restoration process of real initiatives can be informed by the concepts taught in the training program and that the resulting social and ecological outcomes, though not fully realised, are positive.

The evaluation of process elements confirmed that the restoration initiatives reflect what is taught in the training program, providing further support for the suggestion made by scholars that the application of resilience concepts to ecological restoration is possible (Zellmer & Gunderson, 2008; Suding, 2011). It also suggests that these concepts, once applied to an aquatic ecosystem restoration context, can then be taught in a training program, applied in restoration initiatives, and finally, evident in an evaluation of restoration process. This finding adds to the very limited number of examples identified through a review of the ecological restoration and social-ecological resilience literature in Chapter Two, in which resilience thinking concepts have been translated into practice specifically in an ecological restoration context. The fact that the presence and magnitude of evidence is not mirrored between the training program and each of the initiatives appears to support the popular view that moving from resilience thinking to resilience practice, while very important, comes with many challenges and is not an easy task (Cumming et al., 2005; Miller et al., 2010; Walker & Salt, 2012; Plummer et al., 2014b). Furthermore, it implies that context plays an important role in determining which principles are more or less applicable in certain phases for each initiative.

Although a restoration process informed by principles for building resilience in SES is conceptually sound, without empirically evaluating the subsequent expression on the landscape in terms of social and ecological outcomes, it remains unknown whether this new approach ultimately leads to desired outcomes or not. This evaluation of the restoration initiatives' early outcomes in relation to social-ecological resilience responds to the resounding call from scholars for meaningful evaluation of restoration outcomes

(Kondolf & Micheli, 1995; Palmer et al. 2005; Woolsey et al., 2007; Suding, 2011; Nilsson & Aradóttir, 2013). Moreover, this evaluation utilized a framework acknowledging both ecological and social outcomes, something that many scholars have argued needs to happen more often (Woolsey et al., 2007; Aronson et al., 2010; Suding, 2011; Wortley et al., 2013; Perring et al., 2015). In doing so, the findings from the evaluation suggest that restoration initiatives informed by social-ecological resilience do in fact result in positive outcomes. It should be noted, however, that the evaluation of outcomes in terms of social-ecological resilience was subject to some of the same challenges associated with more traditional approaches to evaluation of restoration outcomes (e.g., lag time, attribution issues, lack of detailed baseline data) (Kondolf, 1995; Choi, 2004; Suding, 2011; Wortley et al., 2013). Some of these challenges, such as the delay in the realisation of restoration outcomes, are simply a result of the nature of ecological restoration (Clewell & Aronson, 2013) while others, a lack of detailed baseline data for instance, could be avoidable with careful planning.

The restoration initiatives' positive outcomes, although only a snapshot of early signals, are an encouraging sign for restoration informed by social-ecological resilience as they provide empirical evidence substantiating the claims of scholars who have been pushing for the incorporation of resilience concepts in ecological restoration (Suding et al., 2004; Palmer et al., 2005; Harris et al., 2006; Zellmer & Gunderson, 2008; Seavy et al., 2009; Perring et al., 2015). Ideally, the restoration initiatives will be evaluated again in the future to capture the full extent of social and ecological outcomes. However, Kapos et al. (2009) suggest that long-term monitoring and evaluation is not always practical and examining key outcomes as predictors of project success is an alternative approach with great potential. The evaluation of early restoration outcomes in this study is a first step in understanding how a restoration process informed by social-ecological resilience manifests on the landscape as a series of social and ecological outcomes.

Chapter Six: Conclusions and Recommendations

6.1 Introduction

Freshwater ecosystems provide services critical to human well-being, yet they are among the most transformed systems on Earth (Carpenter et al., 2011) and are expected to undergo further alteration and exploitation in the coming decades (Vörösmarty et al., 2005; Bates et al., 2008). For this reason, ecological restoration is an important goal, particularly for freshwater ecosystems. However, restoration efforts are not always successful and can even make a situation worse as a result of incomplete knowledge or oversimplified understanding of ecosystems (Hilderbrand et al., 2005; Lake et al., 2007). In contrast to traditional mechanistic and linear views, research on CAS has advanced understanding of systems describing them in terms of complexity, uncertainty, non-linearity, and interconnections between social and ecological domains (Levin, 2013). In capturing many of the advancements made by CAS research, social-ecological resilience (Folke, 2006) is well positioned to inform a new approach to restoration. Evidence of the uptake of social-ecological resilience in ecological restoration is only just beginning to appear. Training for individuals and organizations interested in applying social-ecological resilience principles is nascent at best. In addition, evaluation of an approach to restoration informed by social-ecological resilience is necessary to determine whether such an approach results in improved outcomes.

In response to the aforementioned needs, the purpose of this research was to explore aquatic ecosystem restoration and its evaluation in relation to social-ecological resilience. Three research objectives were associated with this purpose: (1) to conceptually explore how social-ecological resilience may inform aquatic ecosystem restoration and its evaluation; (2) to assess a training program for aquatic ecosystem restoration in relation to social-ecological resilience; and (3) to evaluate aquatic ecosystem restoration initiatives informed by the training program in terms of social-ecological resilience. The final chapter of this thesis begins with a summary of the key contributions made to ecological restoration and resilience scholarship and practice as a result of achieving the research objectives. The following section of the chapter is forward-looking, focusing on recommendations for scholarship and future research, as well as, recommendations for the applied practice of ecological restoration.

6.2 Key Contributions

The development of the conceptual framework guiding this study makes a novel contribution to ecological restoration and resilience scholarship by being the first to bridge these two areas, detailing how social-ecological resilience concepts can be incorporated into aquatic ecosystem restoration. Accordingly, the conceptual framework offers other researchers a starting point for moving forward with further research in this area which will serve to enhance the science of restoration ecology. In addition to illustrating the potential for Biggs et al.'s (2012) principles for building resilience to inform each of the phases of the restoration process leading to outcomes on the landscape, the conceptual framework was also operationalized for, and proved useful in, the assessment of the training program and evaluation of restoration initiatives. As such, it can be utilized by other organizations for the assessment of restoration courses and manuals, as well as, for the evaluation of past and future restoration initiatives.

By offering an alternative approach to restoration that overcomes many of the issues associated with traditional restoration approaches, this study makes a valuable contribution to the practice of ecological restoration. The assessment of the training program and evaluation of restoration initiatives demonstrated that an approach to restoration informed by resilience concepts can be taught in a training program and applied by trainees to real restoration initiatives. Importantly, the evaluation of restoration initiatives informed by resilience concepts revealed positive, albeit early, social and ecological outcomes. Collectively, the findings regarding this alternative approach to restoration provide empirical evidence in support of scholars who have been calling for the incorporation of resilience concepts in ecological restoration as a means of improving restoration outcomes (Zellmer & Gunderson, 2008; Suding, 2011). It cannot be overstated that an approach to restoration informed by social-ecological resilience, while promising, is not a panacea. It does not mean that success is guaranteed or that there is not a great deal more to be learned. Nevertheless, using the same approaches that have been proven ineffective is counterproductive and can be a waste of the often limited resources available. This new approach offers an opportunity to experiment and learn from that experimentation in order to advance the science of restoration ecology and its practice. This is a timely contribution as emphasis is increasingly placed on restoration as a way to tackle the challenge of ecosystem impairment caused by human actions (Perring et al., 2015).

The findings from this study also revealed that the Stream Rehabilitation, From Form to Function Training Program is effective as a means of teaching individuals about an approach to restoration informed by resilience concepts. The assessment of the training program showed the extent to which the principles for building resilience are reflected in what is taught about the phases of restoration process. The evaluation of the initiatives informed by the training program showed evidence of those same principles in much of the restoration process and outcomes of the initiatives. These findings suggest that trainees are applying what they learned in the training program and are benefitting from that application in terms of realizing positive restoration outcomes. Moreover, these findings represent an important contribution to practice by confirming that the TUC training program is an exemplary model for other organizations seeking to inform stewardship activities in their areas.

6.3 Recommendations

Based on the findings of this research, several recommendations and directions for future research are suggested in the following subsections. Recommendations for scholarship and future research directions are presented first followed by recommendations for applied practice.

6.3.1 Scholarship and Future Research

Several avenues for future research have been uncovered as a result of this exploratory study. First, future research should seek to elaborate on the relationship between aquatic ecosystem restoration and social-ecological resilience introduced in this study. As an example, future studies should build on initial efforts to understand how sociopolitical considerations factor into an approach to restoration informed by social-ecological resilience (see for example Zellmer & Gunderson, 2008). The empirical evidence in support of the conceptual framework developed in this study and the encouraging signals from early outcomes of restoration initiatives informed by social-ecological resilience provide the impetus for moving forward with this area of research. This recommendation is intentionally very broad because as previously mentioned, there is a great deal to be learned about the relationship between these two areas of scholarship and being overly prescriptive at this point would only serve to limit potential insights.

Second, future research efforts should build on this study by undertaking a more in depth evaluation of social outcomes. For reasons described in Chapter Three, the evaluation of social outcomes in this study was based on information reported by trainees in the semi-structured interviews. However, existing evaluation methods could be drawn on for this purpose. For example, Bennett (2016) describes several methods for studying perceptions of the social impacts of initiatives. Bennett (2016) asserts that perceptions are an important, yet underutilized form of evidence for adaptive management processes and evidence-based conservation decision-making. The incorporation of more rigorous and more holistic methods of evaluating social outcomes would enhance understanding of this aspect of restoration informed by social-ecological resilience.

As this research focuses on aquatic ecosystem restoration in a Canadian context, the third recommendation for future research is to test the conceptual framework in other restoration contexts. Interest in applying resilience concepts to ecological restoration is not restricted to aquatic ecosystem restoration. Other types of restoration (e.g., tallgrass prairie, meadow, forest) face issues similar to that of aquatic ecosystem restoration as they also pertain to CAS. Testing the conceptual framework with other types of restoration would provide valuable insights on the extent to which social-ecological resilience is reflected in current restoration practices more broadly. Where resilience is informing practices, an opportunity exists to determine if positive outcomes are being realized as a result. As with aquatic ecosystem restoration, this information would help determine whether other types of restoration informed by social-ecological resilience are a worthwhile pursuit and would allow for comparisons and sharing of lessons learned across different types of restoration. In addition to considering various types of restoration, the conceptual framework should be tested in countries other than Canada to understand whether context in terms of location is important.

In evaluating restoration initiatives informed by the training program, this study identified where expressions of the principles for building social-ecological resilience were present in the phases of restoration process and outcomes. As a fourth recommendation, future evaluative research should build on the approach used in this study by measuring and comparing the resilience of a system pre- and post-restoration. Measuring the resilience of SES has been discussed in the resilience literature and whether accurately quantifying resilience is possible and/or desirable is still debated (Carpenter et al., 2005; Cumming et al., 2005; Brand & Jax, 2007; Cutter et al., 2008; Quinlan et al., 2015). An initial exploratory study would help determine whether quantifying the resilience of a SES before and after restoration is possible and would be beneficial.

6.3.2 Applied Practice

Recommendations for applied practice also emerged from the research process and findings. First, and directly related to the Stream Rehabilitation, From Form to Function Training Program, is a recommendation for greater emphasis on a combination of continued mentorship and self-study for trainees who have completed the program. The assessment of the training program revealed evidence of the principles for building resilience in SES throughout the restoration process. Only evidence of the principle 'manage slow variables and feedbacks' in the implementation phase was not found. Understandably, the presence and magnitude of evidence was not mirrored perfectly between the training program and the restoration initiatives. Aquatic ecosystem restoration is not a simple endeavour and given the range of experience of the individuals in the training program, some of the concepts may be new to trainees or diverge from their current understanding of aquatic ecosystems and restoration. In addition, scholars have pointed out how difficult the practical application of resilience concepts can be (Peterson, 2002; Cumming et al., 2005; Miller et al., 2010; Walker & Salt, 2012). Continued guidance and exposure to more restoration initiatives that reflect the concepts taught in the training program, as well as sharing lessons learned from different restoration contexts, would help enforce the training even after a trainee has completed all six workshops. Similarly, trainees should be provided with a list of additional resources to help them learn more about the resilience concepts they are introduced to in the training program. Several publications have appeared in recent years that make these concepts accessible to a general audience (see for example Walker & Salt, 2006; 2012; Moberg & Simonsen, 2014; Krievins et al., 2015; Simonsen et al., 2015) and that would serve as excellent materials for self-study.

The evaluation of ecological outcomes was noted as being limited by the fact that initiatives were only recently completed or were ongoing at the time that this study was undertaken. Therefore, only early outcomes and the trajectory of the systems were evaluated. A more complete evaluation of outcomes is recommended for each initiative in the future. The timing of the evaluation will be different for each initiative and depends on the techniques used. Evaluating future outcomes will allow for a more comprehensive understanding of the outcomes associated with a restoration process informed by social-ecological resilience. The suggested evaluation protocol to carry out this recommendation for each initiative is presented in Appendix H and was determined using the decision-making process (Figure 3.1) described in Chapter Three.

The SER Australasia Chapter published the world's first national standards for ecological restoration in July 2016 (McDonald et al., 2016). The standards detail "(i) the principles that underpin current best practice [in] ecological restoration and (ii) the steps required to plan, implement, and monitor restoration projects to increase their chance of success" (McDonald et al., 2016, p. S7). Resilience concepts are explicitly and implicitly discussed in these standards in reference to SES as opposed to ecological systems alone. Over the remainder of the year, SER Chapters around the world will be working collaboratively to adapt the Australian standards for global use, thereby creating international standards for restoration practice (SER, 2016a). The final recommendation emerging from this study is for the practice of ecological restoration to embrace social-ecological resilience in the development of international standards for restoration practice. This recommendation is based on the findings from this study which have revealed encouraging signs of the potential for ecological restoration informed by social-ecological resilience to produce positive outcomes. Although context is important in terms of exactly how the principles for building resilience are embodied in each restoration initiative, in general the principles are transferable and could, therefore, be incorporated in the standards for restoration practice. The incorporation of resilience concepts in SER Australasia's national standards, developed in partnership with over 300 individuals, groups, government agencies, and industries (SER, 2016a), reinforces the findings from this study and this recommendation.

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Appendices

Appendix A: Breakdown of Data Sources Used

Data Sources Used for Assessment of the Training Program

Overview of the History and Evolution of the Training Program	**Assessment of Training Program**
- TUC website - Publicly available presentations and documents - Personal communications with a key informant	- Transcripts from semi-structured interviews with six individuals involved in the development of the training program - Stream Rehabilitation, From Form to Function Training Program manual (most current version as of fall 2015)

Data Sources Used for Evaluation of the Restoration Initiatives

	Description of Initiative	**Evaluation of Initiative**
RI1	- Transcript from semi-structured interview with a past trainee who was extensively involved in the initiative - Excerpt from the entomologist's final report to CVC on rare Odonata in the Credit River Watershed - Scotsdale Farm website	- Transcript from semi-structured interview with a past trainee who was extensively involved in the initiative - Data from vegetation inventories
RI2	- Transcript from semi-structured interview with a past trainee who is extensively involved in the initiative - Five year restoration plan - Personal observations from volunteer involvement	- Transcript from semi-structured interview with a past trainee who was extensively involved in the initiative - Data from vegetation inventories - Data from temperature monitoring - CVC water and air temperature data - Underwater video footage
RI3	- Transcript from semi-structured interview with a past trainee who is extensively involved in the initiative - Publicly available presentations and documents - Personal observations from volunteer involvement - Five year restoration plan	- Transcript from semi-structured interview with a past trainee who was extensively involved in the initiative - Five year restoration plan

Appendix B: Brock University Research Ethics Board Certificate of Ethics Clearance

Brock University
Research Ethics Office
Tel: 905-688-5550 ext. 3035
Email: reb@brocku.ca

Social Science Research Ethics Board

Certificate of Ethics Clearance for Human Participant Research

DATE:	7/9/2015		
PRINCIPAL INVESTIGATOR:	PLUMMER, Ryan - Environmental Sustainability Research Centre		
FILE:	14-276 - PLUMMER		
TYPE:	Masters Thesis/Project	STUDENT: SUPERVISOR:	Katrina Krievins Ryan Plummer

TITLE: Pushing the boundaries of freshwater ecosystem restoration: evaluating a conservation initiative in terms of social-ecological resilience

ETHICS CLEARANCE GRANTED

Type of Clearance: NEW   Expiry Date: 7/29/2016

The Brock University Social Science Research Ethics Board has reviewed the above named research proposal and considers the procedures, as described by the applicant, to conform to the University's ethical standards and the Tri-Council Policy Statement. Clearance granted from 7/9/2015 to 7/29/2016.

The Tri-Council Policy Statement requires that ongoing research be monitored by, at a minimum, an annual report. Should your project extend beyond the expiry date, you are required to submit a Renewal form before 7/29/2016. Continued clearance is contingent on timely submission of reports.

To comply with the Tri-Council Policy Statement, you must also submit a final report upon completion of your project. All report forms can be found on the Research Ethics web page at http://www.brocku.ca/research/policies-and-forms/research-forms.

In addition, throughout your research, you must report promptly to the REB:

a) Changes increasing the risk to the participant(s) and/or affecting significantly the conduct of the study;
b) All adverse and/or unanticipated experiences or events that may have real or potential unfavourable implications for participants;
c) New information that may adversely affect the safety of the participants or the conduct of the study;
d) Any changes in your source of funding or new funding to a previously unfunded project.

We wish you success with your research.

Approved:

Jan Frijters, Chair
Social Science Research Ethics Board

Note: Brock University is accountable for the research carried out in its own jurisdiction or under its auspices and may refuse certain research even though the REB has found it ethically acceptable.

If research participants are in the care of a health facility, at a school, or other institution or community organization, it is the responsibility of the Principal Investigator to ensure that the ethical guidelines and clearance of those facilities or institutions are obtained and filed with the REB prior to the initiation of research at that site.

Appendix C: Interview Guide – Program Developer

Date:

Interviewee:

Position/Role:

Organization:

Introduction

Thank you for agreeing to participate in this study. I would like to remind you that participation is voluntary and you can choose not to answer any question you do not feel comfortable answering. I would also like to remind you that I will be using an audio recorder to record this interview. You will have the opportunity to review the complete transcript before your data is analyzed.

The purpose of this study is to explore aquatic ecosystem restoration and its evaluation in relation to social-ecological resilience. The Stream Rehabilitation, From Form to Function Training Program (formerly Aquatic Renewal Stream Restoration Training Program) is the case being examined for this study. As an individual involved in the development of the program, I will be asking you a series of questions about how the program was developed and what is taught in the workshops. Do you have any questions before we begin?

If yes, answer questions and then start recording.

If no, start recording.

Interview questions

1. What were some of the reasons for the development of the Stream Rehabilitation, From Form to Function Training Program?

2. How did you get involved in the development of the program?

I am interested in understanding what is taught in the program about undertaking different stages of a restoration initiative. The next few questions are structured around general phases of the restoration process.

3. How are trainees taught to identify problems or the need for restoration/rehabilitation in their system of concern?

    - Are there certain structural or functional characteristics that trainees are taught to look for or consider that might signal the need for restoration/rehabilitation?

4. What does the program teach trainees about defining project goals and objectives?

- Are trainees encouraged to incorporate both social and ecological considerations when developing goals and objectives? What might some of those considerations be?
- Does the program touch on who should be involved in the process of defining goals and objectives and what that process might look like?

5. When it comes time to design a restoration plan, how are trainees taught to undertake this task?

   - Is there any direction given to trainees on who should be involved in designing a restoration plan and what that process/involvement might look like?
   - Are trainees encouraged to incorporate both social and ecological considerations when developing a plan?
   - What are some of the key messages trainees are provided with regarding designing a restoration plan?

6. What instructions are trainees provided with regarding the practical implementation of their restoration plan?

   - Does the training program touch on any social considerations related to the implementation of restoration plans?
   - What sort of guidance are trainees given to improve their chances of successfully implementing their restoration plan?

7. What are trainees taught about monitoring and evaluating a restoration initiative?

   - What should trainees be looking at/for when monitoring a restoration initiative and who should be involved in monitoring?
   - In what ways are trainees taught to use monitoring data and are they encouraged to share that data with others in any form?
   - How are trainees taught to measure and evaluate project success?
   - How is project evaluation information used and are trainees encouraged to share that information with others in any form?

Stop recording.

Thank you for your time. I will be in touch as soon as I have prepared the interview transcript for you to review. If you have any questions or concerns at any time please feel free to contact me using the contact information on your copy of the consent form.

Appendix D: Consent Form – Program Developer

Date: ________________________

Project Title: *Pushing the boundaries of freshwater ecosystem restoration: evaluating a conservation initiative in terms of social-ecological resilience*

Principal Investigator: Dr. Ryan Plummer
Environmental Sustainability Research Centre, Brock University
rplummer@brocku.ca
(905) 688-5550, ext. 4782

Principal Student Investigator: Katrina Krievins
Environmental Sustainability Research Centre, Brock University
katrina.krievins@brocku.ca
(905) 688-5550, ext. 6283
(647) 466-0789

INVITATION
You are invited to participate in a study that involves research. The purpose of this study is to explore how new ways of thinking about and understanding complex adaptive systems can inform aquatic ecosystem restoration and its evaluation.

WHAT'S INVOLVED
As a participant, you will be asked to participate in an interview which is expected to take approximately one hour and will be conducted in person, at a mutually convenient time and location. Interview questions will focus on how and why the Stream Rehabilitation, From Form to Function Training Program (formerly Aquatic Renewal Stream Restoration Training Program) was developed, what trainees in the program are taught, and how the material is presented in workshops. The information will be used to assess the training program in relation to social-ecological resilience. Additionally, you will be asked to share program related materials. Interviews will be recorded using an audio recorder and transcribed for the purpose of data analysis. You will have the opportunity to review the interview transcript and will be asked to sign a form confirming the accuracy of the content and approving the use of the transcript for this study. Follow-up interviews may take place to clarify responses where needed.

POTENTIAL BENEFITS AND RISKS
Possible benefits to you from this study include the provision of important information regarding the impact the Stream Rehabilitation, From Form to Function Training Program is having on the ground and the improvement of aquatic ecosystem restoration initiatives. More broadly, this study will inform ecological restoration theory and practice.

Although individual names will not be used in any reporting, there is a potential risk that identities may be discernible as a result of the nature of the study which connects you to the Stream Rehabilitation, From Form to Function Training Program. Results will be presented using descriptors of organizations and a general descriptor of your position or role (e.g., course developer, instructor, project manager of a restoration initiative) to minimize the potential risk of identification as much as possible.

CONFIDENTIALITY

Your name will not appear in any thesis or report resulting from this study. If you approve and sign off on the use of your interview transcript, quotations may be used and identified by general descriptor and organization descriptor, but not your name. Data collected during this study will be stored in a locked storage cabinet; any computer data will be stored only on the principal student investigator's computer under password protection. Access to this data will be restricted to the principal investigator and principal student investigator. Data will be kept for approximately one (1) year following the completion of a final thesis after which time all data will be destroyed.

VOLUNTARY PARTICIPATION

Participation in this study is voluntary. If you wish, you may decline to answer any questions or participate in any component of the study. Further, you may decide to withdraw from this study at any time and may do so without any penalty or loss of benefits to which you are entitled. Should you choose to withdraw from the study prior to reviewing and approving your interview transcript, all of your data will be destroyed. Conversely, if you choose to withdraw from the study after reviewing and approving your interview transcript, your data will be retained and included in data analysis and the reporting of study results.

PUBLICATION OF RESULTS

Results of this study may be published in professional journals and presented at conferences. In addition, a summary report outlining the research design, salient findings, and implications with an emphasis on applied benefits of the study will be made available to you as a participant. Feedback about this study upon completion will be available from Katrina Krievins or Dr. Ryan Plummer via telephone and email.

CONTACT INFORMATION AND ETHICS CLEARANCE

If you have any questions about this study or require further information, please contact the principal investigator or the principal student investigator using the contact information provided above. This study has been reviewed and received ethics clearance through the Research Ethics Board at Brock University (REB file #14-276). If you have any comments or concerns about your rights as a research participant, please contact the Research Ethics Office at (905) 688-5550 Ext. 3035, reb@brocku.ca.

Thank you for your assistance in this project. Please keep a copy of this form for your records.

CONSENT FORM

I agree to participate in this study described above. I have made this decision based on the information I have read in the Information-Consent Letter. I have had the opportunity to receive any additional details I wanted about the study and understand that I may ask questions in the future. I understand that I may withdraw this consent at any time.

Name: ______________________________________
Signature: ___________________________________ Date: ________________

Appendix E: Transcript Release Form

I, ______________________________, have reviewed the complete transcript of my personal interview in this study, and have been provided with the opportunity to add, clarify, and delete information from the transcript as appropriate. I acknowledge that the transcript accurately reflects what I said in my personal interview with Katrina Krievins and that I am aware that by signing this form I agree to the retention of my data if I withdraw from the study. I hereby authorize the release of this transcript to Katrina Krievins to be used in the manner described in the Consent Form. I have received a copy of this Transcript Release Form for my own records.

______________________________	______________________________
Name of Participant	Date
______________________________	______________________________
Signature of Participant	Signature of Researcher

If you have any questions about this study or require further information, please contact the principal investigator or the principal student investigator using the contact information provided below.

This study has been reviewed and received ethics clearance through the Research Ethics Board at Brock University (REB file #14-276). If you have any comments or concerns about your rights as a research participant, please contact the Research Ethics Office at (905) 688-5550 Ext. 3035, reb@brocku.ca.

Principal Investigator:	Dr. Ryan Plummer Environmental Sustainability Research Centre, Brock University rplummer@brocku.ca (905) 688-5550, ext. 4782
Principal Student Investigator:	Katrina Krievins Environmental Sustainability Research Centre, Brock University katrina.krievins@brocku.ca (905) 688-5550, ext. 6283 (647) 466-0789

Appendix F: Interview Guide – Trainee

Date:

Interviewee:

Position/Role:

Organization:

Introduction

Thank you for agreeing to participate in this study. I would like to remind you that participation is voluntary and you can choose not to answer any question you do not feel comfortable answering. I would also like to remind you that I will be using an audio recorder to record this interview. You will have the opportunity to review the complete transcript before your data is analyzed.

The purpose of this study is to explore aquatic ecosystem restoration and its evaluation in relation to social-ecological resilience. The Aquatic Renewal Stream Restoration Training Program is the case being examined for this study with restoration initiatives informed by the training program serving as subunits or embedded cases within the main case. As an individual extensively involved in a restoration initiative informed by the training program, I will be asking you a series of questions about the various stages of the project. Do you have any questions before we begin?

If yes, answer questions and then start recording.

If no, start recording.

Interview questions

8. Can you start by giving me a broad overview of the restoration initiative and your involvement in it before we break it down into a number of stages?

The next few questions are structured around general phases of the restoration process from problem identification through to monitoring and evaluation.

9. (a) What problems/issues were identified that indicated a need for restoration/rehabilitation? (b) How were they identified?

    - Who was involved in the identification of the problem/need for restoration?

10. What were the project goals and objectives and how were they decided on?

    - What did the process look like (e.g., deliberation, decision-making) and who was involved?

- Was consideration given to both social and ecological values?

11. (a) How was the restoration plan designed?
    (b) Were any alternative designs considered?

    - Who was involved in designing the restoration plan, providing input and/or alternative designs, and deciding on the final design?
    - Did the plan consider social and ecological values?
    - Why was the final plan chosen over alternative designs and how was that decision made?

12. (a) What was involved in the implementation of the restoration plan?
    (b) Who was involved and in what ways?

    - Were any steps taken to inform organizations or individuals about the project who were not actively involved in it?
    - How were negative impacts associated with implementing the restoration plan avoided or addressed (at the restoration site and upstream and downstream)?

13. Has any monitoring been completed at the restoration site (before, after, or during restoration) or are any monitoring activities planned?

    - Who is involved in monitoring and decisions about monitoring?
    - How were certain monitoring activities chosen over others?
    - How is monitoring data used and shared?

14. How have you, or will you, evaluate project outcomes?

    - What criteria (social and/or ecological) are being used to evaluate project success/effectiveness?
    - What will evaluation information be used for and who will it be shared with?

15. Can you describe any social outcomes of the restoration initiative so far?

    - Have you seen any evidence of:
        - learning or a shift in the way people understand/relate to the system of concern;
        - experimentation (in relation to the system of concern);
        - greater participation (in relation to the system of concern); or
        - collaboration between organizations?

Stop recording.

Thank you for your time. I will be in touch as soon as I have prepared the interview transcript for you to review. If you have any questions or concerns at any time please feel free to contact me using the contact information on your copy of the consent form.

Appendix G: Consent Form – Trainee

Date: ________________________

Project Title: *Pushing the boundaries of freshwater ecosystem restoration: evaluating a conservation initiative in terms of social-ecological resilience*

Principal Investigator: Dr. Ryan Plummer
Environmental Sustainability Research Centre, Brock University
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Principal Student Investigator: Katrina Krievins
Environmental Sustainability Research Centre, Brock University
katrina.krievins@brocku.ca
(905) 688-5550, ext. 6283
(647) 466-0789

INVITATION

You are invited to participate in a study that involves research. The purpose of this study is to explore how new ways of thinking about and understanding complex adaptive systems can inform aquatic ecosystem restoration and its evaluation.

WHAT'S INVOLVED

As a participant, you will be asked to participate in an interview which is expected to take approximately one hour and will be conducted in person, at a mutually convenient time and location. Interview questions will focus on the details of how the restoration initiative you led or were involved in was undertaken from the planning stages through to monitoring and evaluation of outcomes. Additionally, you will be asked for permission to visit the restoration site in order for a site assessment to be completed. The information will be used to evaluate the restoration initiative in terms of social-ecological resilience. Interviews will be recorded using an audio recorder and transcribed for the purpose of data analysis. You will have the opportunity to review the interview transcript and will be asked to sign a form confirming the accuracy of the content and approving the use of the transcript for this study. Follow-up interviews may take place to clarify responses where needed.

POTENTIAL BENEFITS AND RISKS

Possible benefits to you from this study include the provision of important information regarding the impact the Stream Rehabilitation, From Form to Function Training Program (formerly Aquatic Renewal Stream Restoration Training Program) is having on the ground and the improvement of aquatic ecosystem restoration initiatives. More broadly, this study will inform ecological restoration theory and practice.

Although individual names will not be used in any reporting, there is a potential risk that identities may be discernible as a result of the nature of the study which connects you to the Stream Rehabilitation, From Form to Function Training Program. Results will be presented using descriptors of organizations and a general descriptor of your position or role (e.g., project manager of a restoration initiative, program developer, instructor) to minimize the potential risk of identification as much as possible.

CONFIDENTIALITY

Your name will not appear in any thesis or report resulting from this study. If you approve and sign off on the use of your interview transcript, quotations may be used and identified by general descriptor and organization descriptor, but not your name. Data collected during this study will be stored in a locked storage cabinet; any computer data will be stored only on the principal student investigator's computer under password protection. Access to this data will be restricted to the principal investigator and principal student investigator. Data will be kept for approximately one (1) year following the completion of a final thesis after which time all data will be destroyed.

VOLUNTARY PARTICIPATION

Participation in this study is voluntary. If you wish, you may decline to answer any questions or participate in any component of the study. Further, you may decide to withdraw from this study at any time and may do so without any penalty or loss of benefits to which you are entitled. Should you choose to withdraw from the study prior to reviewing and approving your interview transcript, all of your data will be destroyed. Conversely, if you choose to withdraw from the study after reviewing and approving your interview transcript, your data will be retained and included in data analysis and the reporting of study results.

PUBLICATION OF RESULTS

Results of this study may be published in professional journals and presented at conferences. In addition, a summary report outlining the research design, salient findings, and implications with an emphasis on applied benefits of the study will be made available to you as a participant. Feedback about this study upon completion will be available from Katrina Krievins or Dr. Ryan Plummer via telephone and email.

CONTACT INFORMATION AND ETHICS CLEARANCE

If you have any questions about this study or require further information, please contact the principal investigator or the principal student investigator using the contact information provided above. This study has been reviewed and received ethics clearance through the Research Ethics Board at Brock University (REB file #14-276). If you have any comments or concerns about your rights as a research participant, please contact the Research Ethics Office at (905) 688-5550 Ext. 3035, reb@brocku.ca.

Thank you for your assistance in this project. Please keep a copy of this form for your records.

CONSENT FORM

I agree to participate in this study described above. I have made this decision based on the information I have read in the Information-Consent Letter. I have had the opportunity to receive any additional details I wanted about the study and understand that I may ask questions in the future. I understand that I may withdraw this consent at any time.

Name: ________________________________
Signature: ______________________________ Date: ____________________

Appendix H: Evaluation of Restoration Outcomes

RI1

Principle	Expression(s) of the Principle	Method(s) for Evaluating Expression(s) of the Principle
Maintain diversity and redundancy	Diversity in the planted species	Results/products: compile a vegetation inventory including woody species (trees and shrubs) in a quadrat that covers the entire planted area. Using the same size quadrat, create a woody vegetation inventory for the reference area (roughly where the female clamp-tipped emeralds were seen laying eggs). Calculate the Shannon entropy for both areas. Compare the restoration site value to the reference area value to determine if the planted area can be considered diverse relative to the reference area. Effects: inventory the restoration and reference areas 5 and 10 years post-restoration to see if diversity has changed with natural succession and mortality.
	Diversity in structure (i.e., vertical stratification and age)	Results/products: use the list of species from the restoration area woody vegetation inventory and research each species' growth rate, average life span, and height. Categorize species based on existing classification systems and determine whether or not the species represent a mix of categories. Effects: evaluate structure 10 and 15 years post-restoration using the Ecological Land Classification field sampling method for stand characteristics (Lee et al., 1998). Determine whether the various layers (e.g., sub-canopy, understory) are represented, acknowledging that the canopy and sub-canopy layers will take many years to become fully established.
	Planted species capable of contributing to improving water retention capacity	Results/products: use the list of species from the restoration area woody vegetation inventory and research each species' ability to contribute to the function of improved water retention capacity. Determine whether the species selected for the restoration area are capable of contributing to this function. *Due to large gaps in available information, the water retention capacity of inventoried species in the restoration area could not be included in the evaluation of this initiative. Effects: compare baseline soil moisture regime (Ontario Centre for Soil Resource Evaluation, 1993) to the moisture regime 10 and 15 years post-restoration. Determine if there has been a shift in soil moisture regime in the restoration area towards a wetter regime.
	Planted species with different tolerances to disturbance	Results/products: use the list of species from the woody vegetation inventory and research the tolerances of the different species to ten disturbances and generalist pests. Compare the tolerances of the species in the restoration area to the tolerances of the species in the reference area to make a determination regarding whether or not the degree of response diversity in the restoration area is sufficient. Effects: document the responses of species after a disturbance or pest outbreak has been experienced to

		understand whether or not the species in the restoration area actually exhibit response diversity. Depending on the kind and severity of the disturbance or pest outbreak, documenting the responses could be done with survival monitoring or an assessment of woody species' health pre- and post-disturbance.
Manage connectivity	Restoration area contributing water to the perennial stream	Effects: compare baseline soil moisture regime (Ontario Centre for Soil Resource Evaluation, 1993) to the moisture regime 10 and 15 years post-restoration. Determine if there has been a shift in soil moisture regime in the restoration area towards a wetter regime.
Manage slow variables and feedbacks	Landscape capable of holding more water	Effects: compare baseline soil moisture regime (Ontario Centre for Soil Resource Evaluation, 1993) to the moisture regime 10 and 15 years post-restoration. Determine if there has been a shift in soil moisture regime in the restoration area towards a wetter regime, indicating a modification to the process of infiltration.

RI2

Principle	**Expression(s) of the Principle**	**Method(s) for Evaluating Expression(s) of the Principle**
Maintain diversity and redundancy	Benthic macroinvertebrate diversity	Results/products: conduct a pebble count to observe changes in substrate composition following the installation of silt traps. Determine whether there is a shift towards coarser substrate which would indicate improved habitat for greater diversity of benthic macroinvertebrates. *Due to a lack of available baseline data, a comparison of substrate composition could not be included in the evaluation of this initiative at the time of this study. Effects: use the same benthic sampling and analysis protocol used in each of the five years of monitoring during the initiative to collect benthic data 2 and 5 years post-restoration. Compare the data over the years to identify any shifts in the proportion and diversity of sensitive taxa (e.g., percent EPT) over time. Also compare results to the reference reach.
	Presence of benthic macroinvertebrates with different tolerances	Effects: use the data collected for benthic macroinvertebrate diversity and research the tolerances of the different groups present. Determine whether there are different tolerances among the groups of benthic macroinvertebrates present and if/how this has changed from baseline. Document the responses of the different groups of benthic macroinvertebrates after a disturbance has been experienced (e.g., sampling post-disturbance) in order to understand whether or not response diversity is actually exhibited.
	Diversity in the planted species	Results/products: compile a vegetation inventory including woody species (trees and shrubs) in a quadrat that covers the planted portion of the restoration reach. Using the same size quadrat, create a woody vegetation inventory for the reference reach. Calculate the Shannon entropy for both reaches. Compare the restoration reach value to the reference reach value to determine if the planted area can be considered diverse relative to the reference area. Effects: inventory the restoration and reference reaches 5 and 10 years post-restoration to see if diversity has

		changed with natural succession and mortality.
	Diversity in structure (i.e., vertical stratification and age)	Results/products: use the list of species from the restoration reach woody vegetation inventory and research each species' growth rate, average life span, and height. Categorize species based on existing classification systems and determine whether or not the species represent a mix of categories. Effects: evaluate structure 10 and 15 years post-restoration using the Ecological Land Classification field sampling method for stand characteristics (Lee et al., 1998). Determine whether the various layers (e.g., sub-canopy, understory) are represented, acknowledging that the canopy and sub-canopy layers will take many years to become fully established.
	Presence of riparian vegetation with different tolerances	Results/products: use the list of species from the woody vegetation inventory and research the tolerances of the different species to ten disturbances and generalist pests. Compare the tolerances of the species in the restoration reach to the tolerances of the species in the reference reach to make a determination regarding whether or not the degree of response diversity in the restoration area is sufficient. Effects: document the responses of species after a disturbance or pest outbreak has been experienced to understand whether or not the species in the restoration reach actually exhibit response diversity. Depending on the kind and severity of the disturbance or pest outbreak, documenting the responses could be done with survival monitoring or an assessment of woody species' health pre- and post-disturbance.
	In-stream habitat diversity	Results/products: take underwater video footage at each of the habitat structures installed in 2015. View the video footage for evidence of fish using the structures to determine whether in-stream habitat diversity has been enhanced. Effects: use the Rapid Assessment Methodology for Channel Structure (RAM) (Stanfield, 2013) in the restoration reach to collect data on in-stream habitat diversity at the completion of the restoration initiative and 5 years post-restoration. Compare the data to baseline to determine whether in-stream habitat diversity has improved from baseline.
	Silt traps and plantings both contributing to lowering stream temperatures	Results/products: take temperature measurements over a 12 hour period in the same reach where temperature is recorded by a CVC data logger each year. Compare temperature ranges and average hourly rates of change for the same day in 2014, 2015, and 2016. Determine whether an increase, decrease, or no change has been experienced. A decrease in the range and hourly rate of change from 2014 and 2015 to 2016 would be considered an early sign of the silt traps and riparian plantings contributing to the function of lowering stream temperatures. Effects: compare baseline peak summer water temperature, average hourly rate of temperature change, width to depth ratios (W:D), pool depths, and canopy coverage to 2, 5, and 10 years post-restoration. If peak summer temperature and average hourly rate of change are decreasing over time, the channel is narrowing

		and deepening, and canopy coverage is increasing, silt traps and riparian plantings can be considered factors contributing to the lowering of stream temperatures.
	Silt traps and habitat structures both contributing to habitat creation /enhancement	Effects: compare baseline habitat to habitat 2 and 5 years post-restoration using the RAM, cross-sections for pool depths, pebble counts for substrate composition, and benthic macroinvertebrate sampling for feeding habitat. If there is more and/or better habitat available after the completion of the initiative, silt traps and habitat structures can be considered contributing factors.
Manage connectivity	Availability and use of brook trout habitat	Effects: use data from the RAM to assess availability of habitat, and yearly spawning surveys and electrofishing data to determine actual use of that habitat. Compare baseline data to 2 and 5 years post-restoration to determine whether the availability and use of habitat has increased and whether the species using the habitat have changed.
	Stream returning to dynamic equilibrium	*Focus on narrowing and deepening* Effects: conduct a Rapid Geomorphic Assessment (RGA) and compare results to the reference reach. Compare baseline cross-sectional profiles and W:D 2, 5, and 10 years post-restoration. If there are signs of narrowing and flushing, as opposed to continued widening or no change, the stream can be said to be tending towards dynamic equilibrium. *Focus on balancing erosion and deposition* Effects: compare the baseline stability index score from the RGA to 2, 5, and 10 years post-restoration and to the reference reach to see how much, if any, change has taken place. Determine whether the stream is tending towards becoming dynamically stable. Compare baseline pebble count data (i.e., D_{15}, D_{50}, D_{84}) to 2 and 5 years post-restoration at established cross-sections. Also compare post-restoration and reference reach data. Determine whether the D_{50} is shifting towards larger substrate as fine sediment is flushed.
	Riparian vegetation providing canopy cover and shading the channel	Effects: compare baseline canopy coverage or canopy coverage in the reference reach to coverage 5, 10, and 15 years post-restoration. Determine whether canopy coverage is increasing over time and is tending towards coverage similar to the reference reach.
	Continuous riparian corridor of a sufficient width	Effects: compare baseline riparian corridor quality using an established method (e.g., Munné et al.'s (2003) Riparian Forest Quality index, González del Tánago & de Jalón's (2011) River Quality Index) to 5, 10, and 15 years post-restoration and to the reference reach. Determine whether the continuity and width of the riparian corridor is increasing and whether it appears to be on a trajectory towards matching the reference reach.
Manage slow variables and	Feedbacks perpetuating	Effects: compare baseline cross-sectional profiles, W:D, and D_{50} to 2, 5, and 10 years post-restoration. Determine whether there are signs of narrowing and flushing, as opposed to continued widening or no

feedbacks	undesirable widening of the channel are disrupted	change, which would indicate that undesirable feedbacks have been disrupted.

RI3

Principle	**Expression(s) of the Principle**	**Method(s) for Evaluating Expression(s) of the Principle**
Maintain diversity and redundancy	Benthic macroinvertebrate diversity	Results/products: conduct a pebble count to observe changes in substrate composition following efforts to flush sediment. Determine whether there is a shift towards coarser substrate which would indicate improved habitat for greater diversity of benthic macroinvertebrates. *Due to a lack of available baseline data, a comparison of substrate composition could not be included in the evaluation of this initiative at the time of this study. Effects: use the same benthic sampling and analysis protocol used in past years to collect benthic data every two years. Compare the data over the years to identify any shifts in the proportion and diversity of sensitive taxa (e.g., percent EPT) over time. Also compare results to the reference reach.
	Presence of benthic macroinvertebrates with different tolerances	Effects: use the data collected for benthic macroinvertebrate diversity and research the tolerances of the different groups present. Determine whether there are different tolerances among the groups of benthic macroinvertebrates present and if/how this has changed from baseline. Document the responses of the different groups of benthic macroinvertebrates after a disturbance has been experienced (e.g., sampling post-disturbance) in order to understand whether or not response diversity is actually exhibited.
	Fish species diversity	Results/products: compare baseline data regarding fish species diversity to data collected after the wild brook trout transfer. Determine whether the wild fish transfer, habitat enhancement, and water quality improvements have resulted in greater fish species diversity and/or a shift in the community. Effects: continue collecting fish species diversity data (e.g., electrofishing, spawning surveys, observational data) and compare to baseline over the next 5-10 years to determine whether coldwater species are able to survive and successfully spawn in the watershed.
	Presence of fish species with different tolerances	Results/products: use the fish species diversity data and research the thermal tolerances of the species present. Determine whether there are different tolerances among the species present and if/how this has changed from baseline (e.g., see if there has been a shift towards inclusion of coldwater species). Effects: continue collecting fish species diversity data (e.g., electrofishing, spawning surveys, observational data) and compare to baseline over the next 5-10 years to determine whether the species present have different thermal tolerances.

	In-stream habitat diversity	Results/products: use qualitative descriptions of the availability of brook trout habitat in the watershed, accounts of the restoration work done in Emerson Creek in 2015, and the results of 2015 spawning surveys and 2016 portable PIT tag antenna surveys to determine whether in-stream habitat diversity has been improved. The addition of habitat that was not previously available and/or the enhancement of existing habitat would suggest greater in-stream habitat diversity. Effects: use the Rapid Assessment Methodology for Channel Structure (RAM) (Stanfield, 2013) in the restoration reach to collect data on in-stream habitat diversity at the completion of the 5 year restoration plan and 5 years post-restoration. Compare the data to baseline to determine whether in-stream habitat diversity has improved from baseline.
Manage connectivity	Stream returning to dynamic equilibrium	*Focus on narrowing and deepening* Effects: conduct a RGA and compare results to a reference reach. Compare baseline cross-sectional profiles and W:D 2, 5, and 10 years post-restoration. If there are signs of narrowing and flushing, as opposed to continued widening or no change, the stream can be said to be tending towards dynamic equilibrium. *Focus on balancing erosion and deposition* Effects: compare the baseline stability index score from the RGA to 2, 5, and 10 years post-restoration and to the reference reach to see how much, if any, change has taken place. Determine whether the stream is tending towards becoming dynamically stable. Compare baseline pebble count data (i.e., D_{15}, D_{50}, D_{84}) to 2 and 5 years post-restoration at established cross-sections. Also compare post-restoration and reference reach data. Determine whether the D_{50} is shifting towards larger substrate as fine sediment is flushed.
	Availability and use of brook trout habitat	Effects: use data from RAM to assess availability of habitat, and electrofishing data, spawning survey data, data from PIT tag antenna surveys, and incidental observations to determine actual use of that habitat. Compare baseline data to data collected over the next 5-10 years to determine whether the availability and use of habitat has increased and whether the species using the habitat have changed.
	Absence of barriers to flow where beaver bafflers were installed	Results/products: use information available on presence or absence of barriers to flow to determine whether beaver bafflers installed in July 2010 were successful in discouraging beavers from damming the channel again. No signs of new beaver dams would indicate that connectivity between upstream and downstream areas has been maintained.
Manage slow variables and feedbacks	Feedbacks that maintain desirable system configurations are strengthened	Results/products and effects: compare baseline cross-sectional profiles, W:D, and D_{50} over the next 5-10 years. Determine whether there are signs of narrowing and flushing, as opposed to continued widening or no change, which would indicate that undesirable feedbacks have been disrupted. *Due to a lack of available baseline data, a comparison of cross-sectional profiles, W:D, and D_{50} could not be included in the evaluation of this initiative at the time of this study.

Appendix I: Categories Summarizing Evidence of the Principles from the Assessment of the Training Program

Maintain diversity and redundancy

1. Monitor biodiversity and take steps to maintain or enhance it (20)
   "Restoring native species begins with determining the cause of the loss and whether this cause has been or can be resolved. Then consideration for restoration of the species can proceed." – Training manual
2. Identify where and how habitat diversity and redundancy have been lost or reduced and seek to restore or enhance them (12)
   "Organisms are not separate from their environment, so one of the principles to sound rehabilitation is ensuring that each species and its community have the elements needed for their entire life cycles from a healthy natural system." – Training manual
3. Individuals and groups with diverse perspectives, values, and knowledge have a stake in the watershed and should be included in the restoration process (11)
   "I think what we tried to get people to realize is that there's a lot of people that have a stake in it whether they want to recognize that or not and what they're expecting to do may or may not fly with other people in the community." – Program Developer F
4. Achieving desired outcomes may require a combination of techniques used simultaneously or in sequence (5)
   "In some instances no one technique is adequate. Many stream rehabilitation problems require a set of techniques applied in a particular order, in the correct locations over an extended period of time." – Training manual
5. Multidisciplinary and multi-stakeholder partnerships enhance capacity to understand and resolve issues (3)
   "...the importance of working with professionals in the various agencies and between various disciplines is stressed to improve the ability to understand the issues and possible solutions. A professional can include someone in a specific discipline such as engineering, river morphology, biology, chemistry, or planning." – Training manual
6. Consider response diversity in plan design (1)
   "Stocking is the least preferred choice given issues of genetic quality, conditioning and maladaptation to natural conditions of the hatchery stock." – Training manual

Manage connectivity

1. Understand how dynamically stable channels function and seek to restore balance between sediment and flow regimes in degraded channels (42)
   "...then the instructors specifically talk about the diagnostic features that you would see if a channel is changing its equilibrium form. You'll be able to identify things that are changing but are things that you would expect in a dynamically stable system" – Program Developer A
2. Analyze ecological pathways to determine where there may be discontinuities that need to be addressed (30)
   "Analyzing ecological pathways can determine which ones are or are not functioning in this particular watershed. Some watersheds, depending on their make-up will naturally have some pathways that are not there. Other watersheds will have broken or lost pathways because of human activities." – Training manual
3. Share information through a network of relevant stakeholders within and beyond the watershed and

seek input and feedback (22)
"Within the partnerships, within the partners, within the community, we very much speak to the need to share information." – Program Developer D

4. Certain situations require reducing connectivity to improve the health of the stream (6)
"Creation of buffer strips, fencing of cattle (with landowner permission and support) as well as creation of riparian zones and off-channel wetlands can help to reduce both sediment and nutrient loadings to streams and improve water quality." – Training manual

5. Consider the degree of connection desired between the restoration site and the broader landscape (2)
"The safety of an environment particularly where there will be people becomes very important because if you create an attractant in the environment and somebody gets in there and drowns, you're liable. Creating a natural channel could be construed as attracting people to an area as it will." – Program Developer A

6. Create modularity in the project team by dividing up tasks and distributing the workload (2)
"You don't have one person running the whole thing – we would go through the whole scenario of having a committee and assigning tasks." – Program Developer F

Manage slow variables and feedbacks

1. Monitoring as a specific form of feedback (15)
"...it's kind of like a feedback loop in terms of assessing for success. So you know if it worked, why did it work? Or if didn't work, kind of you know, go back. So there's kind of a feedback loop there." – Program Developer E

2. Selection of techniques to disrupt or dampen undesirable feedbacks (11)
"Deflecting or redirecting high velocity streamflow are two other solutions to reducing or mitigating excessive bank erosion and also can be used to restore meander patterns." – Training manual

3. Hard engineering creates undesirable feedbacks resulting in the need for continuous maintenance (4)
"We stressed, for example, one thing you want to avoid is starting to armour banks to prevent erosion completely because you're just going to transfer that energy downstream which could cause more problems." – Program Developer E

4. An actively adjusting channel creates a feedback loop maintaining the need for further adjustment (1)
"Streams that are actively adjusting can generate enormous sediment discharges that act as a feedback loop for more erosion." – Training manual

5. Understand changes in slow variables over time (1)
"The next step involves a review of existing information and the local history of the watershed to determine how the river has changed over the last 10-100 years. The present state of the stream is likely a result of a history of various activities and interests that have pushed/pulled the stream channel into its present day state." – Training manual

6. Design plans based on the full potential of the system as determined by the slow variables (1)
"A plan that uses the present condition as the baseline will over time allow the system to further degrade as each new generation takes the present conditions resulting from past loss as the new baseline (i.e., degradation creep). Trying to determine the full potential of a system helps to determine if the plan is achieving a net gain towards the potential of the system or just slowing down the rate of decline." – Training manual

Foster complex adaptive systems thinking

1. Context plays a critical role in each phase of the restoration process (62)
"We kept stressing, don't take that cookbook approach. You know, really go back to the problems and

the issues and then try to work on what will solve those" – Program Developer E

2. Design plans based on an understanding of past and present conditions at the focal scale and the scales above and below (43)
"Understanding the historical changes to the watershed as well as recent and potentially future changes is necessary in order to determine what solutions or treatments to apply to the stream in order to restore function..." – Training manual

3. Work with the stream's natural tendencies to restore form and function (31)
"...rehabilitation for a specific species whether it's a fish, an amphibian, a plant, whatever it is, is really short-term thinking in that the long-term stability in any one species is contingent on the stability of form and function of the ecosystem itself. So what we really are trying to instill in people is the rehabilitation of form and function and that everything else comes along..." – Program Developer D

4. Appreciate the complexity of these systems and encourage an adaptive approach to restoration (26)
"Any decision, in part, is a hypothesis and the results of the action can be measured through monitoring to assess how well the action worked. If it did not work, monitoring will give direction on why the desired outcome was not achieved and how to modify the approach in the future." – Training manual

5. Acknowledge that change and surprise are inevitable and may occur naturally (20)
"One of the things we stressed was that erosion, for example, is a natural process, that streams move, they meander, they erode on the outside bends, they deposit on the inside bends. So that, you know, that whole dynamic equilibrium of stream channel change, that was stressed that erosion and sedimentation are natural processes and stream channels will move." – Program Developer E

6. Think and plan long-term recognizing that systems display variability over time as well as space and that system response is not always immediate (17)
"Working with a river's natural tendencies sometimes means allowing it the time to adjust. Rehabilitation work is the beginning of the rehabilitation process, not necessarily the end." – Training manual

7. Gain an understanding of how the different ecological processes within the system work and how they function together as a whole (15)
"I think what you've got to do is give people an understanding of how the system works ecologically and how water functions and how systems function. Then you can start looking at what potentially are the problems." – Program Developer F

8. Consider both ecological and social aspects of the system and how they interact (14)
"...the physical design of a project involves the utilization of data and resources gathered from partners, agencies or from field work combined with an understanding of the ecological, physical and social processes acting on a waterbody." – Training manual

9. Variability and diversity within a system is natural and beneficial, reducing that variability can have many negative consequences (6)
"In-stream habitat degradation is the result of straightening, leveeing, lining, dredging, roads/utility crossings, and dams that alter and simplify the structural characteristics and dynamic processes that create and maintain habitat." – Training manual

10. Problems may have multiples causes and/or multiple possible solutions and may require the use of a suite of techniques (6)
"People recognized that there's not one answer or one solution for every problem, there's lots of different ones." – Program Developer F

11. Encourage resilient systems (2)

“...the recommended plan is simply to ensure that the stream and its corridor are resilient enough to allow adjustment to natural disturbances and urge people not to build or develop in these corridors.” – Training manual

Encourage learning and experimentation

1. Explain the purpose and process of the project to stakeholders and be open to input (19)
   “People like to know why and what is planned in a rehabilitation program. Bringing interested people from your organization and others together and discussing how to proceed is an important step. Timely discussions that occur early on will lead to buy-in and support for each endeavour.” – Training manual
2. Establish mentoring partnerships to facilitate the acquisition of new knowledge and skills (13)
   “But the intent was to have the information collected in a suitable method that an expert could analyze it and then the volunteers would be along to learn from that and have it explained as it was being analyzed so that they would have some context for their work and the situation of their stream.” – Program Developer C
3. Share project monitoring and evaluation information widely (12)
   “Following the rehabilitation works, continued communication of intent and communication of success will help ensure the longevity of the project and aid with the credibility and growth of the group.” – Training manual
4. Monitor changes over the long-term and recognize that there may be lag time between project completion and outcomes (7)
   “One of the greatest learning opportunities is to observe the response of a stream to a design over a period of years: things change.” – Training manual
5. Build a community of practice related to stream rehabilitation (5)
   “...one of the points of this was to try to build up a community of practice related to stream rehabilitation in Ontario.” – Program Developer B
6. Be willing to make mistakes and learn by doing (3)
   “Enough cannot be said about the importance and necessity of planning every project and learning from that experience in order to improve as an organization in the rehabilitation of streams. Mistakes will be made. Be prepared to ask for help. Learn by doing, with humility.” – Program materials
7. Be open to innovation and experimental techniques (2)
   “Then they’ll get critiqued on whether the approach was close, whether it was right or whether it was wrong or whether they came up with something innovative that you know, nobody had thought of before.” – Program Developer F

Broaden participation

1. Seek partnerships with professionals for expert advice and mentorship (48)
   “... once you come up to some conclusions that perhaps erosion is excessive in some areas or deposition is excessive then go back to these people that you’ve sought as mentors and ask them if they could confirm your conclusions.” – Program Developer E
2. Engage the appropriate agencies and individuals to secure permits, approvals, and permissions (27)
   “Once you’ve got that all set out, the next step is to look at approvals process because you can’t just go out there and do things.” – Program Developer A
3. Identify and bring together diverse stakeholders to negotiate project plans (22)
   “We really encouraged partnership and we asked them initially when they were developing their overall goal and objectives to kind of list the other stakeholders who would be interested or could

either benefit from or in another way, perhaps may not be happy with what they're doing – and try to seek those folks out and keep them informed and ask them how they would like to contribute." – Program Developer E

4. Seek information from a variety of sources (18)
   "...it tries to reflect people back or push people back to policies, back to previous plans, back to information that's already prepared rather than bringing up a brand new program so to speak that may or may not be applicable." – Program Developer F
5. Inform relevant stakeholders of the purpose, status, and outcomes of projects (17)
   "In order to gain permission to do good work to restore healthy environments, connecting with the local community and providing the community with good information on their local watershed, river and streams can provide community support for the work." – Training manual
6. Involve experts from a diverse range of disciplines (16)
   "Although informed volunteers and competent professionals can do a great deal, many problems require an interdisciplinary team of professionals because major problems will require more than one discipline's expertise to solve." – Training manual
7. Find opportunities to involve volunteers in projects (10)
   "One of the simplest tools at a community's disposal is to organize stream clean-up days. This approach is considered very beneficial by landowners and can be the starting point to engaging the local community in support of any future work planned." – Training manual

Promote polycentric governance systems

1. Engagement with multiple governing bodies is required to obtain formal approvals and permits as well as formal and informal permission (12)
   "Permission for work on public properties is required from multiple agencies." – Training manual
2. Project deliberations and decision-making should involve agencies and individuals with various sources of authority and expertise (11)
   "All projects, involving instream channel or flow modification, need to be reviewed by a professional and approvals will likely be required by environmental/conservation/natural resource agencies." – Training manual
3. Keep approval agencies informed on the status of the project (1)
   "It may be communicated to the approval agencies so that they understand that what they have approved is or is not working. That's an important step in keeping the institutions on side." – Program Developer A
4. Be aware of vertical nesting of applicable legislation (1)
   "It is important to understand that federal legislation supersedes provincial legislation, which poses some problems related to permitting... This superseding of legislation is similar to the superseding of municipal bylaws by conservation authorities..." – Training manual

Appendix J: RI1 Woody Vegetation Inventory Species' Tolerances

Species	Type of Disturbance or Pest										Sources
	Drought	Flooding	Wind	Ice Storms	Shade	Browsing	Heat	Fire	Gypsy moth	ALHB	
Species present in the restoration and reference area											
Thuja occidentalis	✓	✓	✓	✓	✓	X	✓	X	✓	✓	Daigle & Havinga, 1996; NPCA, 2013; Barnes & Wagner, 2011; Rich et al., 2007; Hauer et al., 1993; Hofmeyer et al., 2009; Carey, 1993; Johnston, 1990; BSWCD, 2015; Lechowicz & Mauffette, 1986; OFAH/OMNR, 2012a
Sambucus canadensis	✓	✓	X	X	✓	✓	✓	X	✓	✓	Halton Region, n.d.; Gilman & Watson, 1994a; Hightshoe, 1988; Daigle & Havinga, 1996; Stevens & Nesom, 2001; Henderson, 1987; Forest Service, 1995
Acer saccharum	X	X	X	X	✓	✓	X	X	X	X	NPCA, 2013; Barnes & Wagner, 2011; Farrar, 2010; Tirmenstein, 1991a; Croxton, 1939; Lemon, 1961; OFAH/OMNR, 2012a, 2012b
Betula papyrifera	✓	X	✓	X	X	X	X	X	X	X	Halton Region, n.d.; Tang & Kozlowski, 1982; Rich et al., 2007; Wingate, 2013; NPCA, 2013; Hutnik & Cunningham, 1965; OFAH/OMNR, 2012b; Uchytil, 1991a; Whitacre, 2008; Lechowicz & Mauffette, 1986; City of Toronto, 2016
Species present only in the restoration area											
Populus balsamifera	X	✓	X	X	X	X	X	X	X	X	Nesom, 2002; Harris, 1990; Barnes & Wagner, 2011; Daigle & Havinga, 1996; Weber & van Cleve, 2005; Hozain et al., 2010; OFAH/OMNR, 2012b; City of Toronto, 2016
Cornus *stolonifera*	✓	✓	✓	✓	X	X	X	✓	✓	✓	City of Toronto, 2012; Lady Bird Johnson Wildflower Center, 2016b; University of Illinois Extension, 2016b; NPCA, 2013; Daigle & Havinga, 1996; Gucker, 2012; Forest Service, 1995
Viburnum lentago	✓	X	✓	✓	✓	✓	✓	X	✓	✓	City of Toronto, 2012; NPCA, 2013; Barnes & Wagner, 2011; Daigle & Havinga, 1996; Peronto, 2008b; USDA, 2016f; Forest Service, 1995
Quercus rubra	✓	X	✓	X	X	✓	✓	✓	X	✓	Halton Region, n.d.; Kimmerer & MacDonald, 1987; Hauer et al., 1993; Farrar, 2010; NPCA, 2013; Barnes & Wagner, 2011; Tirmenstein, 1991b; Ameye et al., 2012; OFAH/OMNR, 2012b; City of Toronto, 2016
Juglans nigra	X	X	✓	✓	X	✓	✓	✓	✓	✓	Pallardy & Rhoads, 1993; NPCA, 2013; Barnes & Wagner, 2011; Farrar, 2010; van Dersal, 1938; Dudek et al., 1998; Hauer et al., 1993; Coladonato, 1991; Lechowicz & Mauffette, 1986; Sacco, 2004; City of Toronto, 2016

Cephalanthus occidentalis	X	✓	✓	✓	X	✓	X	X	✓	✓	NPCA, 2013; Daigle & Havinga, 1996; University of Illinois Extension, 2016a; Snyder, 1991; Whitacre, 2008; USFWS, 2002; Forest Service, 1995
Malus pumila	✓	✓	✓	✓	✓	X	X	✓	X	✓	Cerny et al., 2002; Burban & Andresen, 1994; Hauer et al., 2006; MDNR, n.d.; CFIA, 2013; Hansen et al., 2007; McManus et al., 1989; City of Toronto, 2016
Species present only in the reference area											
Tsuga canadensis	X	X	X	✓	✓	X	X	✓	X	✓	NPCA, 2013; Daigle & Havinga, 1996; Barnes & Wagner, 2011; Hightshoe, 1988; Anderson & Katz, 1992; Hauer et al., 1993; Lechowicz & Mauffette, 1986; City of Toronto, 2016
Fraxinus americana	✓	✓	X	X	✓	X	✓	X	✓	✓	NPCA, 2013; Gilman & Watson, 1993; Barnes & Wagner, 2011; Farrar, 2010; Schlesinger, n.d.; Sacco, 2004; Griffith, 1991; City of Toronto, 2016
Cornus alternifolia	X	✓	X	X	✓	✓	X	X	✓	✓	USDA, 2016b; Gargiullo, 2007; Lady Bird Johnson Wildflower Center, 2016a; Barnes & Wagner, 2011; Peronto, 2008c; Canadian Wildlife Federation, 2016; Forest Service, 1995
Acer spicatum	X	X	✓	✓	✓	✓	X	X	✓	X	Hightshoe, 1988; USDA, 2016a; Barnes & Wagner, 2011; Farrar, 2010; Sullivan, 1993; Pijut, 2004; Sjöman et al., 2015; Lechowicz & Mauffette, 1986; OFAH/OMNR, 2012a
Ribes triste	X	✓	✓	✓	✓	✓	X	X	X	✓	USDA, 2016d; CVC, 2010; Ulev, 2006; University of Idaho Extension, 2016; Smreciu et al., 2013
Fagus grandifolia	X	X	✓	X	✓	✓	✓	X	X	✓	Urban & Shugart, 1992; Tubbs & Houston, 1990; Melancon & Lechowicz, 1987; Barnes & Wagner, 2011; Farrar, 2010; Lechowicz & Mauffette, 1986; City of Toronto, 2016
Tilia americana	✓	✓	✓	X	✓	X	X	X	X	✓	Gilman & Watson, 1994c; Sullivan, 1994c; Hightshoe, 1988; Barnes & Wagner, 2011; Farrar, 2010; Kershaw, 2001; Hauer et al., 1993; Lechowicz & Mauffette, 1986; City of Toronto, 2016
Ulmus americana	✓	✓	✓	X	✓	✓	✓	X	X	X	Bey, n.d.; Barnes & Wagner, 2011; Farrar, 2010; Hauer et al., 1993; Coladonato, 1992; Lechowicz & Mauffette, 1986; City of Toronto, 2016
Acer saccharinum	✓	✓	X	X	X	✓	✓	X	X	X	Barnes & Wagner, 2011; Farrar, 2010; Sjöman et al., 2015; Hauer et al., 1993; OFAH/OMNR, 2012b; Sullivan, 1994a; Lechowicz & Mauffette, 1986

Appendix K: RI2 Woody Vegetation Inventory Species' Tolerances

Species	Type of Disturbance or Pest										Sources
	Drought	Flooding	Wind	Ice Storms	Shade	Browsing	Heat	Fire	Gypsy moth	ALHB	
Species present in the restoration and reference reaches											
Thuja occidentalis	✓	✓	✓	✓	✓	X	✓	X	✓	✓	Daigle & Havinga, 1996; NPCA, 2013; Barnes & Wagner, 2011; Rich et al., 2007; Hauer et al., 1993; Hofmeyer et al., 2009; Carey, 1993; Johnston, 1990; BSWCD, 2015; Lechowicz & Mauffette, 1986; OFAH/OMNR, 2012a
Salix spp.	X	✓	X	X	X	✓	X	✓	X	X	Wenger, 1984; van Dersal, 1938; Farrar, 2010; Hauer et al., 2006; Whitacre, 2008; Barnes & Wagner, 2011; Hansen et al., 2007; OFAH/OMNR, 2012b; CFIA, 2016
Cornus stolonifera	✓	✓	✓	✓	X	X	X	✓	✓	✓	City of Toronto, 2012; Lady Bird Johnson Wildflower Center, 2016b; University of Illinois Extension, 2016b; NPCA, 2013; Daigle & Havinga, 1996; Gucker, 2012; Forest Service, 1995
Viburnum lentago	✓	X	✓	✓	✓	✓	✓	X	✓	✓	City of Toronto, 2012; NPCA, 2013; Barnes & Wagner, 2011; Daigle & Havinga, 1996; Peronto, 2008b; USDA, 2016f; Forest Service, 1995
Prunus virginiana	✓	X	X	X	✓	✓	X	X	✓	✓	City of Toronto, 2012; Johnson, 2000; Barnes & Wagner, 2011; Hauer et al., 2006; Daigle & Havinga, 1996; Lechowicz & Mauffette, 1986; Peronto, 2008a; Forest Service, 1995; City of Toronto, 2016
Picea glauca	✓	✓	✓	✓	✓	X	✓	X	✓	✓	City of Toronto, 2012; NPCA, 2013; Gilman & Watson, 2006; Hauer et al., 2006; Farrar, 2010; Kershaw, 2001; Barnes & Wagner, 2011; Lechowicz & Mauffette, 1986; Forest Service, 1995; City of Toronto, 2016
Cornus amomum	X	✓	✓	✓	✓	X	✓	✓	✓	✓	NRCS, 2014; University of Illinois Extension, 2016c; *Roberts* Conservation District, 2003; NPCA, 2013; Greenville County, 2013; USDA, 2016c; Forest Service, 1995
Ulmus americana	✓	✓	✓	X	✓	✓	✓	X	✓	X	Bey, n.d.; Barnes & Wagner, 2011; Farrar, 2010; Hauer et al., 1993; Coladonato, 1992; Lechowicz & Mauffette, 1986; City of Toronto, 2016
Ribes americanum	✓	✓	✓	✓	✓	✓	X	X	✓	✓	Knudson, 2010; NRCS, 2010; Roberts Conservation District, 2003; Bratsch & Williams, 2009; Forest Service, 1995; Forest Service, 2004
Rosa multiflora	X	X	✓	✓	✓	X	✓	X	X	✓	Munger, 2002; MDA, 2016; Wenning, 2012; Main et al., 2010; Forest Service, 1995; Forest Service, 2004
Viburnum	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	NPCA, 2013; Kershaw, 2001; Barnes & Wagner, 2011; Booth, 2016;

trilobum											Hansen et al., 2007; Davidson et al., 1999; Forest Service, 2004
Lonicera tatarica	✓	X	✓	✓	✓	✓	✓	✓	✓	✓	City of Toronto, 2012; Predick & Turner, 2008; University of Illinois Extension, 2016d; Tassie & Sherman, 2014; Lorenz et al., 1991; Main et al., 2010; Rosentreter et al., n.d.; Schweitzer, 2014; Forest Service, 2004
Crataegus spp.	✓	✓	✓	✓	X	✓	✓	✓	X	✓	City of Toronto, 2012; NPCA, 2013; Barnes & Wagner, 2011; Farrar, 2010; Forest Service, 1995; Whitacre, 2008; New Jersey Forest Service, 2004; Hansen et al., 2007; Hammond, 2014
Species present only in the restoration reach											
Sambucus canadensis	✓	✓	X	X	✓	✓	✓	X	✓	✓	Halton Region, n.d.; Gilman & Watson, 1994a; Hightshoe, 1988; Daigle & Havinga, 1996; Stevens & Nesom, 2001; Henderson, 1987; Forest Service, 1995
Acer saccharinum	✓	✓	X	X	X	✓	✓	X	X	X	Barnes & Wagner, 2011; Farrar, 2010; Sjöman et al., 2015; Hauer et al., 1993; OFAH/OMNR, 2012b; Sullivan, 1994a; Lechowicz & Mauffette, 1986
Populus tremuloides	X	X	X	X	X	X	✓	X	X	X	Worrall et al., 2013; NPCA, 2013; Perala, 1990; Hauer et al., 2006; Barnes & Wagner, 2011; Garber, 1987; OFAH/OMNR, 2012b; CFIA, 2016
Betula papyrifera	✓	X	✓	X	X	X	X	X	X	X	Halton Region, n.d.; Tang & Kozlowski, 1982; Rich et al., 2007; Wingate, 2013; NPCA, 2013; Hutnik & Cunningham, 1965; OFAH/OMNR, 2012b; Uchytil, 1991a; Whitacre, 2008; Lechowicz & Mauffette, 1986; City of Toronto, 2016
Larix laricina	X	✓	✓	X	X	X	X	X	X	✓	Calco-Polanco et al., 2012; Chalupa, 1991; Hauer et al., 2006; Barnes & Wagner, 2011; Kershaw, 2001; Lechowicz & Mauffette, 1986; Uchytil, 1991b; Hammond, 2014; City of Toronto, 2016
Ulmus rubra	✓	✓	✓	X	✓	✓	✓	X	✓	X	Evergreen, 2014b; Cooley & Sambeek, 1990; Farrar, 2010; Hauer et al., 2006; Barnes & Wagner, 2011; Lechowicz & Mauffette, 1986; Coladonato, 1993; Forest Service, 1995; CFIA, 2016
Picea abies	X	X	X	✓	✓	✓	X	X	✓	✓	Barnes & Wagner, 2011; Farrar, 2010; Iles & Gleason, 1994; Hauer et al., 2006; MacMillan & Detweiler, 2008; Lechowicz & Mauffette, 1986; Sullivan, 1994b; Forest Service, 1995; City of Toronto, 2016
Populus grandidentata	X	X	✓	X	X	✓	✓	X	X	✓	Gustafson et al., 2016; NPCA, 2013; Laidly, 1990; Hauer et al., 2006; Garber, 1987; Texas A&M University, n.d.; OFAH/OMNR, 2012b; Parker et al., 2012
Amelanchier arborea	X	X	✓	✓	✓	✓	X	✓	✓	✓	NPCA, 2013; Chadwick, 2016; Lechowicz & Mauffette, 1986; Whitacre, 2008; Hauer et al., 2006; Forest Service, 1995; Hansen et al., 2007; City of Toronto, 2016; Hammond, 2014
Species present only in the reference reach											
Acer saccharum	X	X	X	X	✓	✓	X	X	X	X	NPCA, 2013; Barnes & Wagner, 2011; Farrar, 2010; Tirmenstein, 1991a; Croxton, 1939; Lemon, 1961; OFAH/OMNR, 2012a, 2012b

Fraxinus nigra	✓	✓	X	X	X	✓	X	✓	✓	✓	Gargiullo, 2007; Farrar, 2010; Gucker, 2005; Hauer et al., 2006; Barnes & Wagner, 2011; Lechowicz & Mauffette, 1986; City of Toronto, 2016
Prunus serotina	✓	X	X	X	X	X	✓	X	✓	✓	City of Toronto, 2012; Marquis, 1990; Nesom, 2000; Hauer et al., 2006; Barnes & Wagner, 2011; Lechowicz & Mauffette, 1986; Gilman & Watson, 1994b; Forest Service, 1995; City of Toronto, 2016
Pinus strobus	X	X	✓	X	✓	X	X	✓	✓	✓	NPCA, 2013; Lemon, 1961; Barnes & Wagner, 2011; Powers et al., 2005; Lechowicz & Mauffette, 1986; Forest Service, 1995; City of Toronto, 2016
Rubus occidentalis	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	Evergreen, 2014a; Gargiullo, 2015; Bailey, 1942; Davidson et al., 1999; Main et al., 2010; Tirmenstein, 1990; USDA, 2016e; Forest Service, 2004
Acer negundo	✓	✓	X	X	X	✓	X	X	X	X	Kershaw, 2001; Barnes & Wagner, 2011; Lechowicz & Mauffette, 1986; Rosario, 1988; Parker et al., 2012
Tilia americana	✓	✓	✓	X	✓	X	X	X	X	✓	Gilman & Watson, 1994c; Sullivan, 1994c; Hightshoe, 1988; Barnes & Wagner, 2011; Farrar, 2010; Kershaw, 2001; Hauer et al., 1993; Lechowicz & Mauffette, 1986; City of Toronto, 2016
Cornus alternifolia	X	✓	X	X	✓	✓	X	X	✓	✓	USDA, 2016b; Gargiullo, 2007; Lady Bird Johnson Wildflower Center, 2016a; Barnes & Wagner, 2011; Peronto, 2008c; Canadian Wildlife Federation, 2016; Forest Service, 1995
Tsuga canadensis	X	X	X	✓	✓	X	X	✓	X	✓	NPCA, 2013; Daigle & Havinga, 1996; Barnes & Wagner, 2011; Hightshoe, 1988; Anderson & Katz, 1992; Hauer et al., 1993; Lechowicz & Mauffette, 1986; City of Toronto, 2016

Appendix L: RI1 Woody Vegetation Inventory Species' Growth Rates, Average Life Spans, and Heights

Species	Growth rate	Average life span	Height		Sources
			Trees	Shrubs	
Thuja occidentalis	Slow-growing	Moderately long-lived	M		Farrar, 2010; Barnes & Wagner, 2011
Viburnum lentago	Moderately fast-growing	Short-lived	S	L	Daigle & Havinga, 1996; Barnes & Wagner, 2011
Cornus stolonifera	Moderately fast-growing	Short-lived		M	Daigle & Havinga, 1996; USDA NRCS, 2008
Acer saccharum	Slow-growing	Long-lived	L		Barnes & Wagner, 2011; NPCA, 2013
Sambucus canadensis	Moderately fast-growing	Short-lived		M	Daigle & Havinga, 1996; NPCA, 2013; Connon Nurseries, 2016
Populus balsamifera	Fast-growing	Short-lived	L		Farrar, 2010; Barnes & Wagner, 2011
Quercus rubra	Fast-growing	Long-lived	M		Kershaw, 2001; Barnes & Wagner, 2011
Cephalanthus occidentalis	Moderately slow-growing	Short-lived	S	M	Daigle & Havinga, 1996; USDA NRCS, 2008; Farrar, 2010
Juglans nigra	Fast growing	Moderately long-lived	L		Barnes & Wagner, 2011; NPCA, 2013
Betula papyrifera	Fast-growing	Moderately short-lived	M		Farrar, 2010; Barnes & Wagner, 2011
Malus pumila	Slow-growing	Moderately long-lived	S		Kershaw, 2001; Barnes & Wagner, 2011

Appendix M: Analysis of RI1 Process and Outcomes

Key Social-Ecological System Properties to be Managed

Principle	Categories Summarizing Evidence of Principles in Restoration Process	Analysis of Ecological Outcomes
Maintain diversity and redundancy	7. Creation and/or enhancement of habitat to support a goal of improving biodiversity (4) *"To increase the availability of water for the dragonfly. There's a damp area and we felt with trees that would become a little bit more wet because a little bit further on there is a running stream. This is an intermittent stream, I guess that we planted and we thought it would help make it full time."* 8. Stakeholders with diverse perspectives, knowledge, and authority working together throughout the restoration process towards a common goal (2) *"Now the exact planning was done in cooperation with the Credit Valley Conservation. So their experts came out and other forestry experts came out and we all had a site meeting with my contact from Ontario Heritage Trust..."* 9. Loss of biodiversity in the watershed identified as a problem (1) *"...[he] was involved through the Credit Valley Conservation on studying some rare types of dragonflies. He did study at Scotsdale Farm and he found there was a rare type of dragonfly there and he suggested to me in discussions that the habitat for this dragonfly, which is fish food, could be improved."* 10. Diversity in the native species selected as part of the restoration plan (1) *"...amongst the three of us we decided we'll have so many Nannyberries, so many Oak trees, and so many Buttonbushes and stuff like that. That was our plan, the detailed plan."*	• The diverse species assemblage in the restoration area, relative to the reference area, fully reflects the criteria for this principle. • The presence of species with a variety of growth rates, life spans, and heights in the restoration area suggests that the area may be on a trajectory towards exhibiting diversity in terms of vertical structure and age structure. • The presence of species in the restoration area with varying tolerances to a variety of disturbances and pests suggests that the area may be on a trajectory towards exhibiting a sufficient degree of response diversity relative to the reference area.
Manage connectivity	7. Building a network of organizations, agencies, and landowners that work together throughout the restoration process with varying degrees and kinds of involvement (4) *"Now the exact planning was done in cooperation with the Credit Valley Conservation. So their experts came out and other forestry experts came out and we all had a site meeting with my contact from Ontario Heritage Trust..."*	• NATA
Manage slow variables and feedbacks	7. Monitoring and capitalizing on changes in slow variables (2) *"...this was an opportunity and we had been working on Ontario Heritage Trust on this property for quite a few years and this was the opportunity so we jumped in and took advantage of it."*	• NATA

Key Attributes of the Governance System

Principle	Categories Summarizing Evidence of Principles in Restoration Process and Social Outcomes
Foster complex adaptive systems thinking	1. Projects are intended to be part of a long-term, large-scale program of restoration (5) *"Yes, and with the intent at the same time to do more. To work with Ontario Heritage Trust to raise some money and do more of that kind of thing."* 2. An adaptive approach to restoration is taken given the fact that conditions and knowledge are constantly changing and uncertainty is pervasive (4) *"I would visit the site and if it looked like half of the trees died I would tell them, quite a large number of trees died, we need to do something different. Then we would contact the forestry people and see well what did we do wrong?"*
Encourage learning and experimentation	1. Openness to trying techniques new to the area and/or project team (5) *"It's essentially abandoned farmland and there were wet areas that we thought we could improve the water retention capacity – so this kind of thing I learned from the course – by putting in some trees"* 2. Long-term monitoring in the watershed brought attention to the need for restoration (4) *"Again, that goes back several years ... he's an entomologist, he works at the Royal Ontario Museum – has been concerned for several years that the mayfly, the Green Drake – I'm trying to think of the scientific name, Ephemera guttulata – has disappeared from some areas of the Credit River."* 3. Volunteer engagement creates opportunities to share information about the watershed and teach new skills (3) *"...the bonus was giving high school kids the opportunity to learn something and contribute to the restoration of the universe."* 4. Partnerships between professionals and volunteer organizations create opportunities for knowledge sharing and learning throughout the restoration process (3) *"Well, they have no expertise in the area so we suggested that this is what we would do, we would put 150 trees in this particular area which we had a map and circled the area that we would do it on and then they got approval."* 5. Potential shift in the way stakeholders understand and relate to the system of concern as a result of the restoration process (2) *"Because of the success of this project and because it didn't cost them anything and it's not hurting anything in their plans. Yea, we very likely will be doing more work."*

Broaden participation	1. Collaboration between groups and individuals with applicable local and scientific knowledge throughout the restoration process (5) *"That was our plan, the detailed plan. Now that was done in cooperation with a forester and with Credit Valley Conservation."* 2. Providing opportunities for interested stakeholders to get involved in the project and acquire new skills (4) *"The trees were planted through the Credit Valley Conservation [Branch Out! program]."* 3. Engaging with the appropriate agencies for approvals (3) *"We worked for quite a few years to get Ontario Heritage Trust to allow us to do this and last year we finally got the approval"* 4. Getting others to see the value in the work and get on board with the project (3) *"We got a favourable report from the contact at Ontario Stewardship and I suggested to him we could do some more in the future and he said "yes, of course". So now we have to raise some money to do that."* 5. Greater collaboration and participation as a goal and/or outcome of the project (2) *"Well yea, it went from 0 to 100% in a year, a couple years."* 6. Sharing information about the outcomes of the project with relevant stakeholders (1) *"...I would visit the site and if it looked like half of the trees died I would tell them, quite a large number of trees died, we need to do something different. Then we would contact the forestry people and see well what did we do wrong?"*
Promote polycentric governance systems	1. Project deliberations and decision-making involve agencies and individuals with various sources of authority and expertise (2) *"Yes, informally and formally through the Stewardship Council. We had our meetings and said this is what we would like to do, we've been trying to get our foot in the door for many years but the actual plan was agreed to and approved by the Stewardship Council."* 2. Working with multiple governing bodies at different scales to obtain the necessary approvals and permission to implement the project plan (1) *"We worked for quite a few years to get Ontario Heritage Trust to allow us to do this and last year we finally got the approval and after signing a 30 page thick agreement to enter document they let us go in there with CVC Conservation Youth Corps."* 3. Greater collaboration between governing bodies as an outcome of the project (1) *"Yes, so it went 0 to 100 in a very quick time. Yes, the cooperation with Ontario Heritage Trust was definitely evident and satisfactory to all parties."*

Appendix N: RI2 Woody Vegetation Inventory Species' Growth Rates, Average Life Spans, and Heights

Species	Growth rate	Average life span	Height		Sources
			Trees	Shrubs	
Thuja occidentalis	Slow-growing	Moderately long-lived	M		Farrar, 2010; Barnes & Wagner, 2011
Salix spp.	Fast-growing		S	L	Farrar, 2010; Barnes & Wagner, 2011
Cornus stolonifera	Moderately fast-growing	Short-lived		M	Daigle & Havinga, 1996; USDA NRCS, 2008
Viburnum lentago	Moderately fast-growing	Short-lived	S	L	Daigle & Havinga, 1996; Barnes & Wagner, 2011
Sambucus canadensis	Moderately fast-growing	Short-lived		M	Daigle & Havinga, 1996; NPCA, 2013; Connon Nurseries, 2016
Prunus virginiana	Slow-growing	Short-lived	S	L	Farrar, 2010; Barnes & Wagner, 2011
Acer saccharinum	Fast-growing	Moderately long-lived	L		Farrar, 2010; Barnes & Wagner, 2011
Picea glauca	Slow-growing	Long-lived	M		Farrar, 2010; Barnes & Wagner, 2011
Cornus amomum	Moderately fast-growing	Short-lived		M	Daigle & Havinga, 1996; NPCA, 2013
Ulmus americana	Fast-growing	Moderately long-lived	L		Farrar, 2010; Barnes & Wagner, 2011
Populus tremuloides	Fast-growing	Short-lived	L		Barnes & Wagner, 2011; NPCA, 2013
Betula papyrifera	Fast-growing	Moderately short-lived	M		Farrar, 2010; Barnes & Wagner, 2011
Ribes americanum	Moderately slow-growing	Short-lived		S	Daigle & Havinga, 1996; Knudson, 2010
Rosa multiflora	Moderately slow-growing	Short-lived		L	FIPRC, n.d.; NH Department of Agriculture, n.d.b
Viburnum trilobum	Moderately fast-growing	Short-lived		L	Daigle & Havinga, 1996; Millcreek Nursery, 2015; Prairie Nursery, 2016
Larix laricina	Fast-growing	Short-lived	M		Farrar, 2010; Barnes & Wagner, 2011
Lonicera tatarica	Moderately slow-growing	Short-lived		M	NH Department of Agriculture, n.d.a
Crataegus spp.	Slow-growing		S	L	Farrar, 2010; Barnes & Wagner, 2011
Picea abies	Moderately fast-growing	Long-lived	L		Farrar, 2010; Barnes & Wagner, 2011
Ulmus rubra	Fast-growing	Moderately long-lived	M		Farrar, 2010; Barnes & Wagner, 2011
Populus grandidentata	Fast-growing	Short-lived	M		Farrar, 2010; Barnes & Wagner, 2011
Amelanchier arborea	Slow-growing	Moderately long-lived	S	L	Farrar, 2010; Barnes & Wagner, 2011

Appendix O: Analysis of RI2 Process and Outcomes

Key Social-Ecological System Properties to be Managed

Principle	Categories Summarizing Evidence of Principles in Restoration Process	Analysis of Ecological Outcomes
Maintain diversity and redundancy	11. Stakeholders with diverse perspectives, knowledge, and authority working together throughout the restoration process towards a common goal (5) *"But then they developed this formal five year plan in concert with the other groups..."* 12. Use of several monitoring techniques to observe changes in biodiversity and the conditions necessary to support the desired biodiversity (4) *"...so we were just out doing a spawning survey this weekend, there was benthic surveys done, temperatures are being logged..."* 13. Creation and/or enhancement of different kinds of habitat to support a goal of improving biodiversity (2) *"... in narrowing the stream, it'll deepen the water which will keep it cooler and then put in habitat structures and some spawning substrate and hopefully increase the brook trout population numbers in that reach, in that area."* 14. Project funding is reliant on more than one source (1) *"...last year CVC applied for some funding for year one. This year...our group, we've put in a few applications."* 15. Variety of means used to share project information with a diverse audience (1) *"So it's mainly through that CVC thing and TU Greg Clark chapter and then obviously through the Aquatic Renewal, I don't know what you call it, it's not a forum."* 16. Loss of biodiversity in the watershed identified as a problem (1) *"...as part of that review they identified that brook trout population numbers seem to be declining throughout the watershed."*	• The diverse species assemblage in the restoration area, relative to the reference area, fully reflects the criteria for this principle. • The presence of species with a variety of growth rates, life spans, and heights in the restoration area suggests that the area may be on a trajectory towards exhibiting diversity in terms of vertical structure and age structure. • The presence of species in the restoration area with varying tolerances to a variety of disturbances and pests suggests that the area may be on a trajectory towards exhibiting a sufficient degree of response diversity relative to the reference area. • The presence of fish at each of the habitat structures indicates that the structures are serving their purpose and may be on a trajectory towards providing enhanced habitat diversity for brook trout. • The decrease in stream temperature range and hourly rate of change from 2014 and 2015 to 2016 is an early sign that the silt traps and riparian plantings are beginning to contribute to the function of lowering stream temperature.

Manage connectivity	8. Building a network of organizations, agencies, and landowners that work together throughout the restoration process with varying degrees and kinds of involvement (5) *"Certainly a big component of the project is collaboration with the partners that I told you about..."* 9. Importance of getting volunteers involved in implementation and monitoring (5) *"Certainly a big component of the project is collaboration with the partners that I told you about and volunteer engagement is huge as you know having gone to them."* 10. Monitoring the balance between sediment and flow regimes following completion of the project (2) *"But also, we're hoping/expecting that when we narrow the river, it should down cut because we're narrowing it, that's just how it works – they either widen or they down cut depending because they have the same volume of water – so we're hoping that it down cuts and flushes out the accumulated stuff and exposes more gravely, cobbley substrates we're hoping that are underneath there. So we would be able to tell if that's starting to happen."* 11. Reducing connectivity in certain situations to improve the health of the system (1) *"... 20 people going through a specific site to plant or whatever, we're actually starting to create trails and paths along the river ... The only way we're trying to mitigate that is to keep everything centralized so it's not all over the place so we don't make tons of paths, we make one to get to the stuff"*	• NATA
Manage slow variables and feedbacks	8. Monitoring as a specific form of feedback (2) *"We didn't do any substrate addition this year but I think we're on schedule to do some next year. Basically put gravels in the bed. So if we did that one year and then we went and monitored it and it's not there anymore, we wouldn't keep putting gravel there, that sort of thing, right?"* 9. Selection of solutions and techniques based on the ability to disrupt feedbacks maintaining undesirable configurations (2) *"...there's been silt trap construction days which is how we're trying to narrow the stream..."* 10. Evaluating project success in part based on whether feedbacks maintaining	• NATA

	undesirable configurations were disrupted (2) *"For temperature, if it's not increasing temperature through the restoration reach like it currently is, that's a success."* 11. Monitoring as a specific form of feedback (2) *"We didn't do any substrate addition this year but I think we're on schedule to do some next year. Basically put gravels in the bed. So if we did that one year and then we went and monitored it and it's not there anymore, we wouldn't keep putting gravel there, that sort of thing, right?"*	

Key Attributes of the Governance System

Principle	**Categories Summarizing Evidence of Principles in Restoration Process and Social Outcomes**
Foster complex adaptive systems thinking	12. An adaptive approach to restoration is taken given the fact that conditions and knowledge are constantly changing and uncertainty is pervasive (2) *"We didn't do any substrate addition this year but I think we're on schedule to do some next year. Basically put gravels in the bed. So if we did that one year and then we went and monitored it and it's not there anymore, we wouldn't keep putting gravel there, that sort of thing..."* 13. Creating favourable conditions for a specific species involves first restoring a healthy system with appropriate form and function (2) *"So I guess the overarching goal is to narrow the stream to the reference conditions that are downstream of the site and in narrowing the stream, it'll deepen the water which will keep it cooler and then put in habitat structures and some spawning substrate and hopefully increase the brook trout population numbers in that reach, in that area."* 14. Problems identified as a result of monitoring system health at multiple scales (1) *"CVC has ongoing monitoring across the watershed and they did a 10-year review of their integrated watershed monitoring program. I think that would be maybe three years ago or so and as part of that review they identified that brook trout population numbers seem to be declining throughout the watershed. This project is on the Credit River which contains one of the populations and their monitoring also showed that the population in this area is declining."*
Encourage learning and experimentation	8. Diverse range of stakeholders involved in monitoring system response during and/or after project completion using a variety of techniques (3) *"Everyone. Everyone could be. So anyone from the project partners could be [involved in monitoring] and we welcome volunteers to come out for any event..."* 9. Volunteer engagement creates opportunities to share information about the watershed and teach new skills (2) *"I would say that every day a new volunteer comes out, they're learning something because we always make a point of explaining what we're doing and why."* 10. Sharing project monitoring and evaluation information widely (2)

	"...if it starts showing success, I'm pretty sure we'll be telling everyone. If we don't show success though, I'm more of a science guy so that's a result too, to me." 11. Long-term monitoring in the watershed brought attention to the need for restoration (1) *"CVC has ongoing monitoring across the watershed and they did a 10-year review of their integrated watershed monitoring program. I think that would be maybe three years ago or so and as part of that review they identified that brook trout population numbers seem to be declining throughout the watershed."* 12. Openness to trying techniques new to the area and/or project team (1) *". So certainly, we're trying to implement best practices and if best practices changed, I think we would do that."*
Broaden participation	8. Collaboration between groups and individuals with applicable local and scientific knowledge throughout the restoration process (7) *"But then they developed this formal five year plan in concert with the other groups to sort of – CVC wanted to sort of hand it off. Say, "we've done some work, there's more work that needs to be done. Let's create a plan and hand it off so that volunteer groups can do it with our help still", that kind of thing."* 9. Providing and promoting opportunities for interested stakeholders to get involved in the project, learn about the watershed, and acquire new skills (7) *"I'm not sure if that's sort of a stated goal of the project but it's certainly the intent – is to build on those relationships and foster those relationships between the different organizations and to engage volunteers and citizens and everything and that sort of stuff."* 10. Greater collaboration and participation as a goal and/or outcome of the project (7) *"...a five year project being implemented the vast majority by volunteers, if we get the five years implemented and everything goes off without a hitch – well, I don't mean without a hitch – but if we actually achieve all the plantings and all the structures and all the things, I would consider that a huge success"*
Promote polycentric governance systems	5. Project deliberations and decision-making involve agencies and individuals with various sources of authority and expertise (1) *"...they developed this formal five year plan in concert with the other groups to sort of – CVC wanted to sort of hand it off. Say, "we've done some work, there's more work that needs to be done. Let's create a plan and hand it off so that volunteer groups can do it with our help still", that kind of thing."*

Appendix P: Analysis of RI3 Process and Outcomes

Key Social-Ecological System Properties to be Managed

Principle	**Categories Summarizing Evidence of Principles in Restoration Process**	**Analysis of Ecological Outcomes**
Maintain diversity and redundancy	17. Creation and/or enhancement of different kinds of habitat to support a goal of improving biodiversity (5) *"Then I guess the third thing is the actual building spawning areas and improving the stream for natural habitat areas and nursery areas for the brook trout."* 18. Stakeholders with diverse perspectives, knowledge, and authority working together throughout the restoration process towards a common goal (3) *"Everybody's been always in touch and we've had to get GRCA approvals for everything we want to do..."* 19. Use of several monitoring techniques to observe changes in biodiversity and the conditions necessary to support the desired biodiversity (3) *"...temperature is the critical one because without the cold temperatures you don't have brook trout, you have a brown trout stream"* 20. Loss of biodiversity in the watershed identified as a problem (2) *"So once they discovered the cold water sources then they started to look at it as a possible brook trout habitat and what was a history of brook trout in the area."* 21. Project funding is reliant on more than one source (2) *"...funding has been applied to a number of groups like TD and so on for money and support to do things."* 22. Creation and/or enhancement of different kinds of habitat to support a goal of improving biodiversity (5) *"Then I guess the third thing is the actual building spawning areas and improving the stream for natural habitat areas and nursery areas for the brook trout."*	• The fish species diversity data are not directly comparable. However, in general terms it can be said that there is greater diversity now that a coldwater species has been observed surviving and spawning in the watershed. The survival of the transferred brook trout suggests that the watershed may be on a trajectory towards supporting a self-sustaining coldwater community and thus, greater species diversity and response diversity. • The creation of spawning habitat in Emerson Creek and its utilization for brook trout redds fully reflects the criteria for this principle.
Manage connectivity	12. Building a network of organizations, agencies, and landowners that work together throughout the restoration process with varying degrees and kinds of involvement (11) *"The main thing, and the good thing, was that every person who is a landowner along that stretch of, I guess that's Mill Creek there, has been you know very*	• The maintenance of unimpeded flow through the reach where beaver dams previously acted as a barrier to flow fully reflects the criteria for this principle.

	enthusiastic in saying, "yea, we agree this is a good idea, how can we help?"" 13. Importance of getting volunteers involved in implementation and monitoring (2) *"But the landowners have done many different things by helping move materials in or clearing pathways for us to get in more easily and things like that."* 14. Reducing connectivity in certain situations to improve the health of the system (4) *"...improving water quality by keeping cattle out of the stream by fencing it off, providing watering sites."* 15. Regular contact with relevant stakeholders is maintained throughout the duration of the project to provide updates and receive feedback (5) *"Everybody's been always in touch and we've had to get GRCA approvals for everything we want to do..."* 16. Addressing discontinuities that restrict the movement of water, sediment, and/or organisms (4) *"I think the other thing involved was sort of cleaning up the stream as well, removing debris, logjams, etc."*	
Manage slow variables and feedbacks	12. Monitoring as a specific form of feedback (5) *"In our case, like the beaver bafflers we installed them once and we found out that in the one location it didn't work very well. You know, we had to learn ourselves how to modify it a bit to make it work for our application."*	• NATA

Key Attributes of the Governance System

Principle	**Categories Summarizing Evidence of Principles in Restoration Process and Social Outcomes**
Foster complex adaptive systems thinking	15. An adaptive approach to restoration is taken given the fact that conditions and knowledge are constantly changing and uncertainty is pervasive (4) *"It was Mill Creek going into Rogers Creek and that was sort of an accidental discovery, finding this little stream and so on, so it's been added on."* 16. Creating favourable conditions for a specific species involves first restoring a healthy system with appropriate form and function (4) *"Then I guess the third thing is the actual building spawning areas and improving the stream for natural habitat areas and nursery areas for the brook trout."*

	17. Problems identified as a result of monitoring system health at multiple scales (1) *"So they did those background studies to augment the initial report of looking at the area."* 18. Monitoring is context specific and relates back to the goals and objectives of the project (1) *"I think it's more that type of monitoring – we're doing this project to do this and then observing whether this actually happens."*
Encourage learning and experimentation	13. Diverse range of stakeholders involved in monitoring system response during and/or after project completion using a variety of techniques (5) *"I would say it's probably observational by the chapter ... Habitat Haldimand and then the landowners as well just all sort of meeting and talking on a casual basis more than a big meeting or anything like that about what's happening, what's changing, what's not changing.."* 14. Openness to trying techniques new to the area and/or project team (4) *"So some of it's new techniques or adaptations of techniques so there's no, "we have to do it this way because we've always done it this way" kind of thing."* 15. Partnerships between professionals and volunteer organizations create opportunities for knowledge sharing and learning throughout the restoration process (3) *"They weren't there all the time but definitely they had an advisory role you know on how things are going to be done. You know, look out for this or do that. Again, sometimes more so like definitely when we were building the spawning areas the rocky ramps and so on, they were there."* 16. Potential shift in the way stakeholders understand and relate to the system of concern as a result of the restoration process (2) *"But I would say in general just because of the work that's being done and the engagement, I would think that the local landowners and other people who have come and taken part and worked on one or more work projects, they've definitely become more aware of what can be done as far as improving watersheds, habitat, and so on."* 17. Sharing project monitoring and evaluation information widely (2) *"There have been articles in "Currents" magazine from Trout Unlimited Canada which is the middle of the "Fly Fusion" and also on the Trout Unlimited website some sort information things that have gone in."*
Broaden participation	11. Collaboration between groups and individuals with applicable local and scientific knowledge throughout the restoration process (8) *"They weren't there all the time but definitely they had an advisory role you know on how things are going to be done. You know, look out for this or do that. Again, sometimes more so like definitely when we were building the spawning areas the rocky ramps and so on, they were there."* 12. Sharing information about the outcomes of the project with relevant stakeholders in the watershed and at the larger scale (4) *"There have been articles in "Currents" magazine from Trout Unlimited Canada which is the middle of the "Fly Fusion"*

	and also on the Trout Unlimited website some sort of information things that have gone in..." 13. Engaging with the appropriate agencies for approvals (4) *"When it came to transferring the fish, definitely MNR was involved there."* 14. Getting others to see the value in the work and get on board with the project (3) *"...I would say that would definitely be an objective because you're not going to be successful unless you get the local landowners to buy in and understand the value of what's happening and how it's beneficial to them and beneficial to everyone in general."* 15. Greater collaboration and participation as a goal and/or outcome of the project (2) *"Oh I think that just the whole project has caused a greater participation of community people and also people like members of Trout Unlimited from the Hamilton area as well."* 16. Providing opportunities for interested stakeholders to get involved in the project, learn about the watershed, and acquire new skills (2) *"But the landowners have done many different things by helping move materials in or clearing pathways for us to get in more easily and things like that. And then, as I say, Trout Unlimited chapter members or even members from Izaak Walton and other areas as well."*
Promote polycentric governance systems	6. Working with multiple governing bodies at different scales to obtain the necessary approvals and permission to implement the project plan (4) *"Yea, at different stages of, you know, what they wanted to do. Definitely they had to get approvals for doing certain things."* 7. Keeping approval agencies informed on the status of the project (3) *"Also, they need to show to MNR who approved this that, yes it was successful and so on so we can add more fish on a yearly basis or you know, add them in another area or whatever."* 8. Information and experiences on common issues are shared among organizations in neighbouring watersheds (1) *"Jack was there and Larry who had done it in another stream in the Mid Grand Chapter and so on. So yea, definitely they had an input and so on to make sure that things were going properly I guess."* 9. Project deliberations and decision-making involve agencies and individuals with various sources of authority and expertise (1) *"...there is a huge amount of collaboration because it involves so many different people because once you start dealing with water, then you have all of the different governments and so on and agencies you know."*